Year-Round Accessibility of the Beaufort Sea from the East via the Southern Route of the North-West Passage
Phase I

Final Report
Ice Climatology and Navigation Assessment

90-06532/

File:5111

Year-Round Accessibility of the Beaufort Sea from the East via the Southern Route of the North-West Passage Phase I

Final Report Ice Climatology and Navigation Assessment

Presented to:

Executive Services Branch
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July 31, 1989

Canadian Coast Guard / Garde côtière canadienne

R&D PROJECT REPORT DOCUMENTATION FORM

1. Transport Canada Report No.	2. CCG Project No.	3. Recipient's Catalogue No.
TP No. 9906 - E		

4. Title and Subtitle	5. Report Date
Year-Round Accessibility of the Beaufort Sea from the East via the Southern Route of the North-West Passage. Phase I - Ice Climatology and Navigation Assessment	July 31, 1989
	6. Performing Organization Report No. CSL 8-5111
7. Author(s) de Bastiani, P. and Bell, A.P.	8. Transport Canada File No.
9. Performing Organization Name and Address Canarctic Shipping Company Limited 1005-350 Sparks St. Ottawa, Ontario K1R 7S8	10. DSS File No. 057SZ.T8080-8-2892
	11. DSS or Transport Canada Contract No T-8080-8-29892/057SZ
12. Sponsoring Agency Name and Address Executive Services Branch Marine Group, Canadian Coast Guard 10th Floor, Canada Building 344 Slater St. Ottawa, Ontario K1A 0N7	13. Type of Report and Period Covered Final Report
	14. Sponsoring Agency Code
15. Supplementary Notes Funding for this project was provided by Program of Energy Research and Development (PERD) Task 6.6	16. CCG Project Officer Mr. wayne Ellwood

17. Abstract

Phase I of the Beaufort Accessibility Program investigated the bathymetric data base currently available to navigators accessing the Southern Route of the North-West Passage. The deep-draft corridor for vessels drawing up to 12 metres narrows to a single track of soundings in Victoria Strait and Cache Point Channel however, these waterways seldom appear to contain dangerous ice. Several new aids to navigation (NAVAIDS) are proposed by the investigating Master Mariner in an effort to improve positioning accuracy along the narrow section of the corridor. Historical vessel transits were reviewed and it was concluded that detailed and accurate ice information is of critical importance to navigators making strategic routing decisions. Detailed documentation of future transits through the North-West Passage would improve the knowledge base on ice/vessel interactions. Three years of winter Synthetic Aperture Radar (SAR) data, collected over the consolidated waterways of the Southern Route (1986-1989), was interpreted. A high degree of inter-annual variability was detected in the ice of Franklin Strait, Larsen Sound and Victoria Strait which was predominately a result of variations in meteorological events affecting summer break-up patterns. It was recommended that detailed physical ice properties data be collection for year-round conditions in the regions to validate detailed remote sensing information of sea ice conditions.

18. Key Words	19. Distribution Statement
North-West Passage, Navigation, Bathymetry, Remote Sensing, Synthetic Aperture Radar (SAR).	

20. Security Classification (of this report)	21. Security Classification (of this page)	22. No. of Pages	23. Price
None	None	56	------

Canada

Garde côtière canadienne | Canadian Coast Guard

FORMULE DE DOCUMENTATION POUR RAPPORT DU PROJET (R&D)

1. N° du rapport Transports Canada	2. N° de l'étude de GCC	3. N° de catalogue du destinataire
TP-No. 9906-E		

4. Titre et sous-titre

Year-Round Accessibility of the Beaufort Sea from the east via the Southern Route of the North-West Passage. Phase I - Ice Climatology and Navigation Assessment.

5. Date du rapport

31 juillet, 1989

6. N° du rapport de l'organisme exécutant

CSL 8-5111

7. Auteur(s)

de Bastiani, P et Bell, A.P.

8. N° de dossier Transports Canada

9. Nom et adresse de l'organisme exécutant

La Compagnie de Navigation Canarctic Limitee
350 Rue Sparks
Suite 1005
Ottawa, Ontario, K1A 0N7

10. N° de dossier – ASC

057SZ.T8080-8-2892

11. N° de contrat – ASC ou Transports Canada

T-8080-8-29892/057SZ

12. Nom et adresse de l'organisme parrain

Services Executifs
Groupe Maritime, Garde Cotiere Canadienne
10 ieme etuge, Canada Building
344 Rue Slater,
Ottawa, Ontario, K1A 0N7

13. Genre de rapport et période visée

Rapport Final

14. Code de l'organisme parrain

15. Remarques additionnelles Le financement de ce projet provient du Groupe interministeriel de recherche et development energetique (GRDE) Comitte 6.6.

16. Agent de projet de GCC

Mr. Wayne Ellwood

17. Résumé

Durant la Phase I du Programme d'Accessibilité à la mer de Beaufort, les données bathymétriques de la Route du Sud du Passage du Nord-Ouest, furent étudiées. Le corridor accessible aux navires ayant un tirand d'eau d'un maximum de 12 mètres, se rétrécis à une seule ligne de sondages dans les régions du Détroit de Victoria et du chenal de Cache Point. Cependant, il semble que ces routes navigables ne soit que rarement encombrées de glaces dangereuses. Plusieurs aides à la navigation (NAVAIDS) ont été proposées par le capitaine au long cours impliqué dans ce programme, dans le but d'améliorer la précision des positions relevées le long des sections étroites des corridors navigables. L'examen de records de passages antérieurs mène à la conclusion que des informations détaillées et précises sur les conditions de glaces sont d'importance critique lors des décisions stratégiques du parcours à suivre. La documentation détaillée de futurs voyages à entreprendre dans le Passage du Nord-Ouest, augmenterait significativement les connaissances des interactions navire/glace. On procéda à l'examen d'images SAR (Synthetic Aperture Radar) des voies navigables gelées de la Route du Sud, accumulées durant trois ans (1986-1989). De grandes différences furent notées entre les conditions de glace de différentes années pour les régions du Détroit de Franklin, du Détroit de Larsen et du Détroit de Victoria. Les différences notées sont principalement dues aux variations climatologiques, lesquelles affectent le régime de débacle durant l'été. Il a été recommandé que des données détaillées sur les propriétés physiques des glaces soient recueillies à l'année longue dans les régions d'intérêt. Ces données serviront à valider l'information détaillée des conditions de glaces obtenus par télédétection.

18. Mots-clés	19. Diffusion
Passage du Nord-Quest, Navigation, bathymetrie, teledetection, Synthetic Aperture Radar (SAR)	

20. Classification de sécurité (de ce rapport)	21. Classification de sécurité (de cette page)	22. Nombre de pages	23. Prix
Aucune	Aucune	56	--------

0338

Canada

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Year-Round Accessibility of the Beaufort Sea from the East via the Southern Route of the North-West Passage

Phase I
Final Report
Ice Climatology and Navigation Assessment

1.0 Introduction:

The many years of exploratory drilling in the Canadian Beaufort Sea have culminated with the announcement of the discovery of large oil and gas fields at Amauligak and Tarsuit. Potential development of Beaufort Sea hydrocarbon supplies in the early 1990's may be based upon the transport of these resources via the marine mode.

One principal route is to transport the oil via icebreaking tankers eastward through the North-West Passage to eastern Canadian markets. The accesssibility of Amundsen Gulf and the Beaufort Sea through the North-West Passage can be via two routes: the Northern Route via Viscount Melville Sound and Prince of Wales Strait; and the Southern Route utilizing Peel Sound, Franklin Strait,Larsen Sound, Victoria Strait, Queen Maud Gulf, Dease Strait, Coronation Gulf, and Dolphin and Union Strait. The Southern Route may be alternately accessed through Prince Regent Inlet and Bellot Strait. The transit routes of the North-West Passage are identified in Figure 1. The region of interest for this study, including the specific waterways of the Southern Route, are identified in Figure 2.

The objective of Phase I of this program is to investigate aspects of the historical ice climatology and navigational environment of the Southern Route of the North-West Passage as they impact on potential year-round navigation by deep-draft

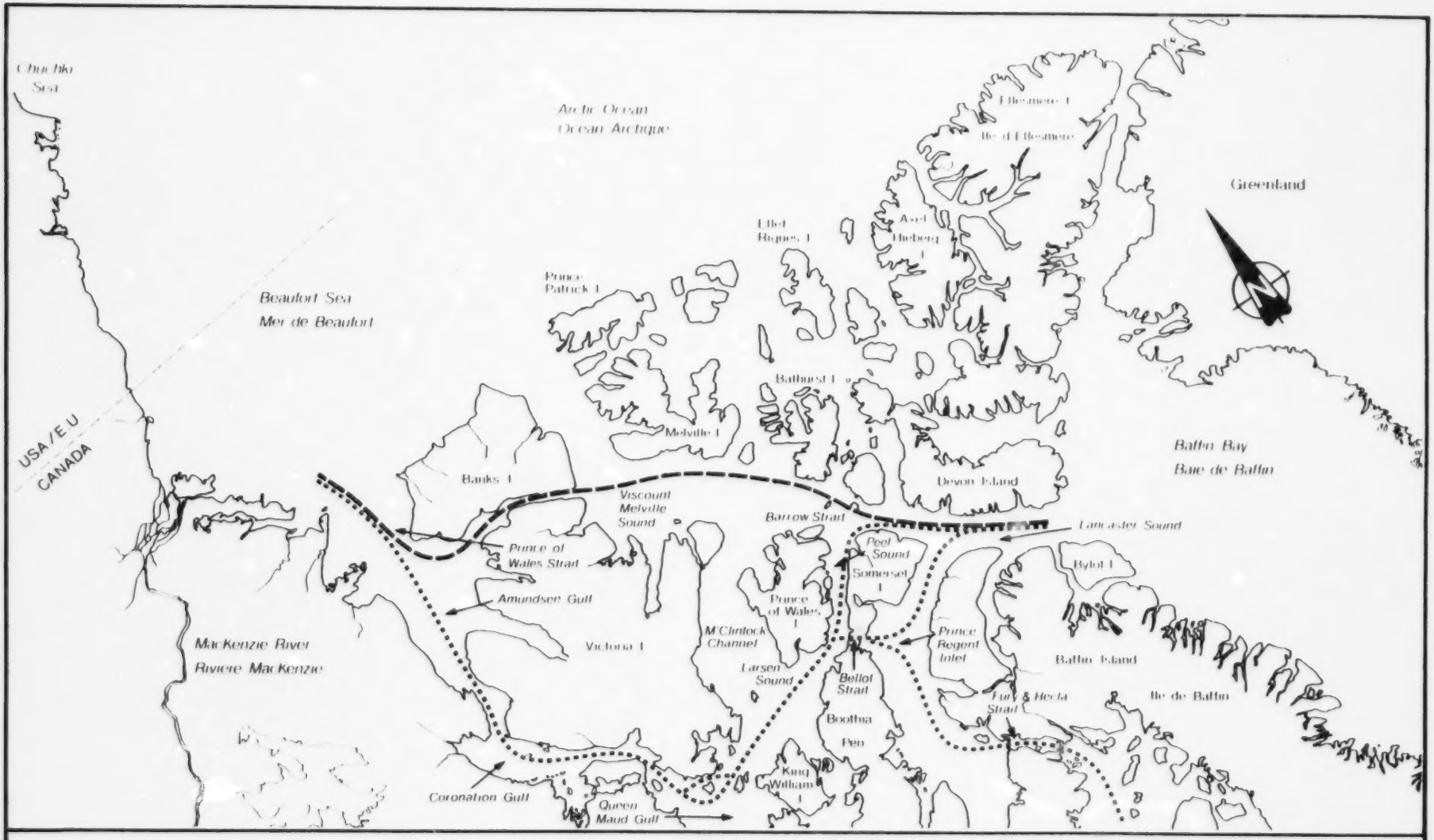

Figure 1: Transit routes of the North-West Passage ——— Northern Route
..... Southern Route

Scale 1: 11,500,000

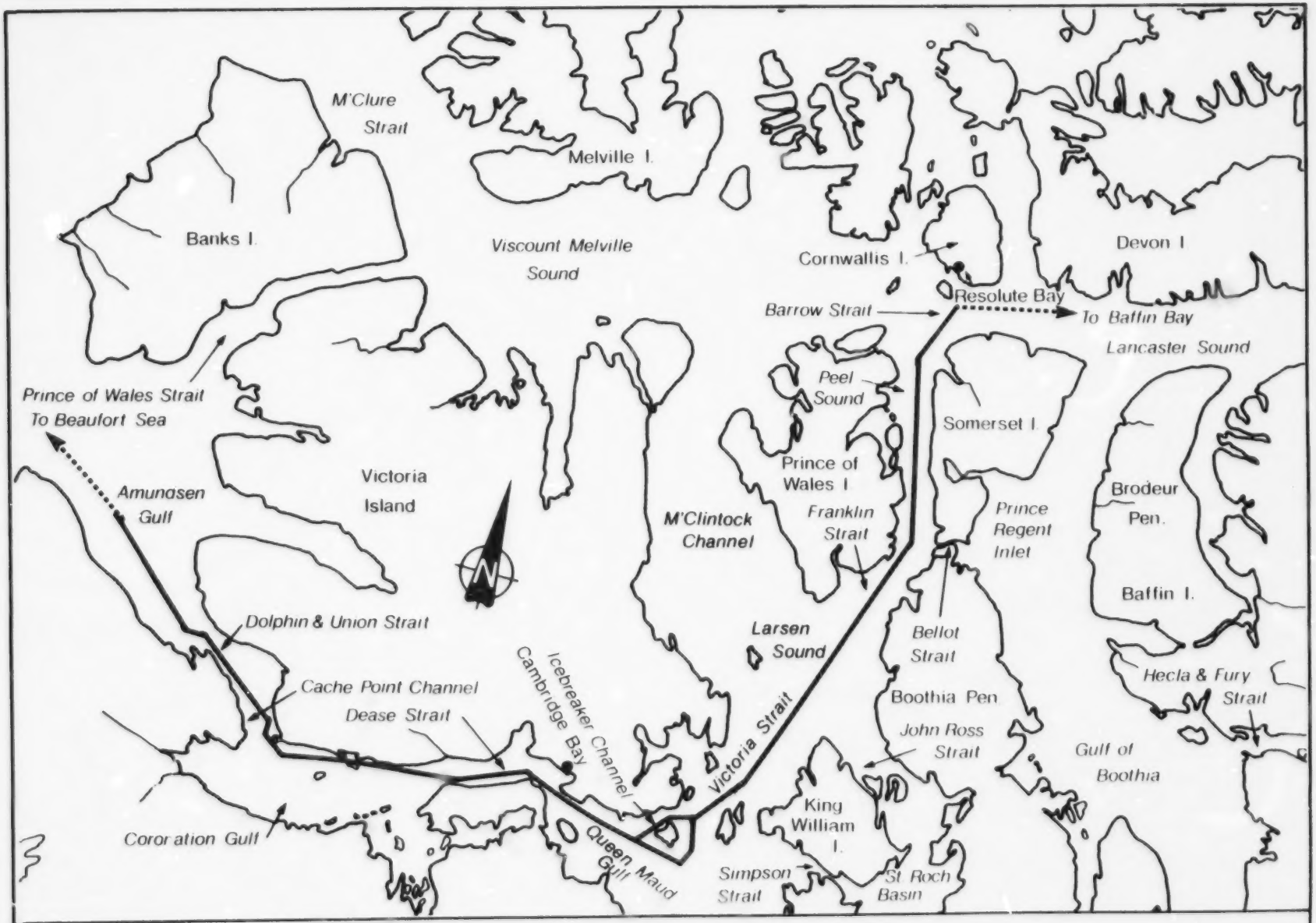

Figure 2: Route for deep-draft vessels through the Southern Route of the North-West Passage

Coverage of ice climatology & bathymetric assessment Scale 1:6,000,000

icebreaking tankers.

This report is comprised of seven sections of which this introduction constitutes the first section. Section 2 presents an assessment of the charted bathymetry along the Southern Route of the North-West Passage and an operational review of the location of aids to navigation maintained presently along the deep-draft corridor. Section 3 investigates the transit experience of vessels which have accomplished historical passages through the Southern Route of the North-West Passage. Section 4 presents an ice climatology analysis of historical and contemporary SAR (Synthetic Aperture Radar) data collected over the waterways of the Southern Route between 1986 and 1989. Section 5 presents the main conclusions and Section 6 the recommendations of the study. References for documents or reports reviewed during Phase I of the study are listed in Section 7. Appendix A contains a complete set of navigation chart reproductions upon which is delineated the deep-draft corridor of the Southern Route.

2.0 Navigation Assessment

The initial task accomplished during this study involved re-visiting a report produced by a Canarctic Master Mariner in 1986. The internal report assessed the Navigable Routes to the Beaufort Sea from the Eastern Arctic (#R-1535, Canarctic 1986). This study provided a preliminary assessment of the viability of operating M.V. ARCTIC (28,000 DWT - Arctic Class 4 equivalency) through both the Northern and Southern Routes of the North-West Passage. The appropriate navigation charts were examined along with information presented in the Sailing Directions - Arctic Canada (Dept. of Fisheries and Oceans, 1981 and 1982).

The overall conclusion of this study confirmed the viability of deep-draft shipping through both routes of the North-West Passage. The study suggested a requirement for the future execution of controlled bathymetric surveys along the waterways of the Southern Route in order to improve the accuracy of the charts. The study also proposed the deployment of passive radar reflectors at specific headlands in the Victoria Strait region in order to improve position fixing.

During this phase of the Beaufort Accessibility Study the navigation charts covering the waterways of the Southern Route were reviewed in detail to accurately plot the deep-draft corridor. This task assisted the definition of ongoing requirements for the execution of detailed surveys. The task also assisted the specification of proposed locations for the deployment of additional aids to navigation.

2.1 The Bathymetric Data Base

Figure 3 shows the coverage of currently available nautical charts for the waterways of the Southern Route. Table 1 lists the currently available charts of specific interest to navigators attempting passage through the region. The charts represent the bathymetric data base investigated under this task.

The Canadian Hydrographic Service (CHS) has recently re-organized the scale and coverage of several bathymetric charts for the Southern Route region. New charts will be issued in 1989 (personal communication - Mr. S. Crother, CHS, December 15, 1988). The new charts will not contain new soundings, however charted depths in fathoms will be replaced with the appropriate SI units (metres). Figure 4 delineates the coverage of the new nautical charts and Table 2 lists the charts which will be of specific interest to navigators attempting to transit the

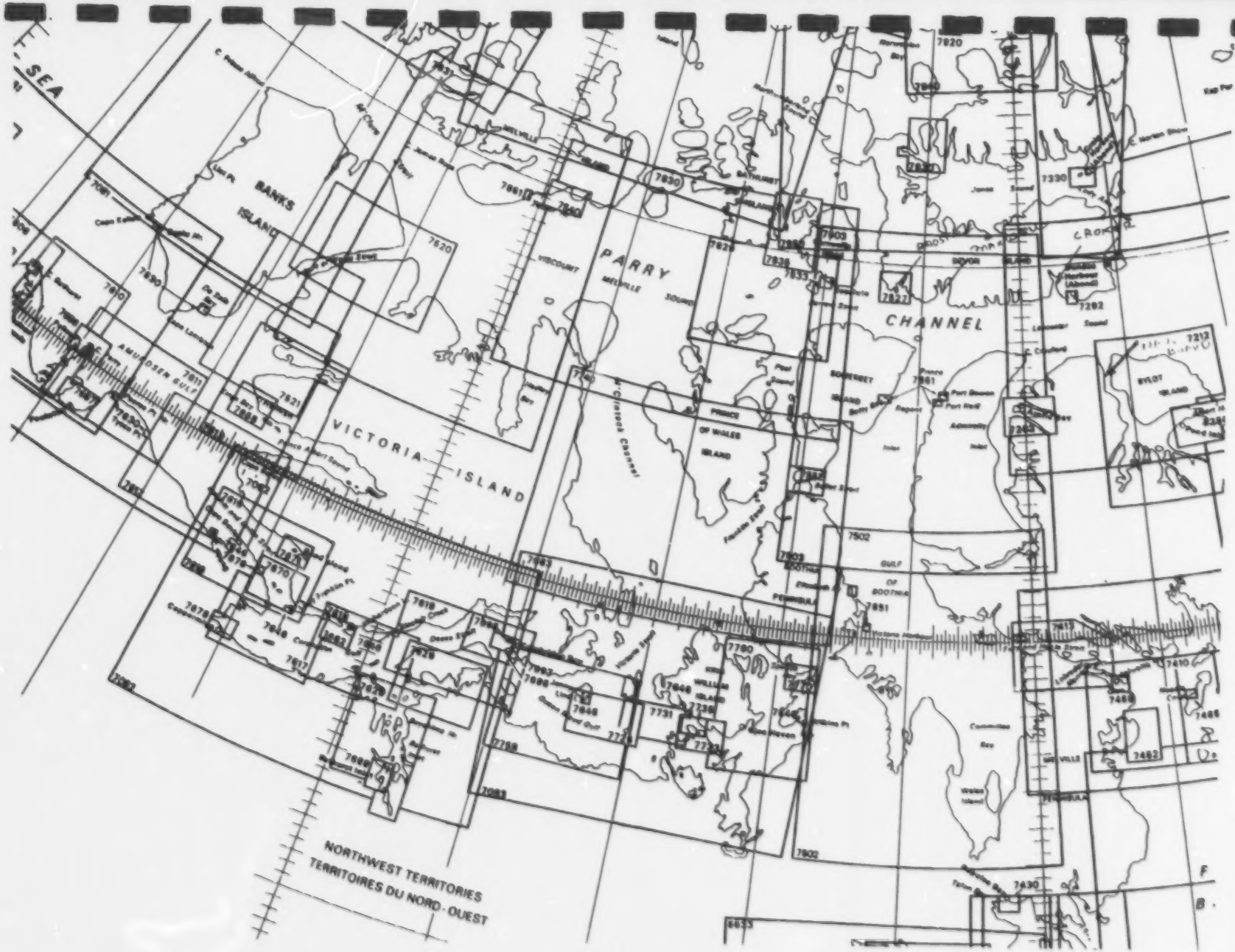

Figure 3 - Nautical charts currently available for the waterways of the southern route of the North-West Passage (Catalogue of Nautical Charts and related Publications, #4 Arctic, Canadian Hydrographic Service, 1985).

Table 1

Currently available navigation charts for waterways of the Southern Route of the North-West Passage (Catalogue of Nautical Charts and Related Publications, #4 Arctic, Canadian Hydrogrpahic Service, 1985).

Chart #	Area of Coverage	Scale	Units of Charted Soundings
7083	Cambridge Bay to Shepherd Bay	1:500,000	fathoms
7612	Tysoe Point to Cape Bexley	1:200,000	metres
7616	Dolphin and Union Strait	1:150,000	metres
7617	Coronation Gulf, Western Portion/Partie Ouest	1:150,000	metres
7618	Coronation Gulf, Eastern Portion/Partie Est	1:150,000	metres
7619	Dease Strait	1:200,000	metres
7670	Bernard Harbour to Cady Franklin Point	1:75,000	metres
7682	Edinburgh Channel and Approaches	1:50,000	metres
7725	Requisite Channel and Approaches	1:75,000	metres
7740	M'Clintock Channel, Larsen Sound and/et Franklin Strait	1:500,000	metres
7758	Melbourne Island to Hat Island	1:200,000	metres
7830	Cornwallis Island to Stefansson Island	1:500,000	metres

Figure 4 - Nautical charts which will become available in 1989, for the waterways of the southern route of the North-West Passage (Catalogue of Nautical Charts and related Publications, #4 Arctic, Canadian Hydrographic Service, 1988).

Table 2

Navigation charts available in 1989 for the waterways of the Southern Route of the North-West Passage (Catalogue of Nautical Charts and Related Publications, #4 Arctic, CHS 1988). N.B. All soundings are in metres (N.B. all charts will present sounding in metres).

Chart	Area of Coverage	Scale
7710	Lambert Channel and/et Cache Point Channel	1: 80,000
7750	Approaches to/Approaches a Cambridge Bay	1: 80,000
7776	Dolphin and Union Strait	1:150,000
7777	Coronation Gulf, Western Portion/ Partie Ouest	1:150,000
7778	Coronation Gulf, Eastern Portion/ Partie est	1:150,000
7779	Dease Strait	1:150,000
7780	Melville Sound	1:150,000
7782	Queen Maud Gulf Western Portion/ Partie Ouest	1:150,000
7783	Queen Maud Gulf Eastern Portion/ Partie Est	1:150,000

Southern Route of the North-West Passage.

Between March 1 and May 1, 1989 a helicopter based research bathymetric survey was undertaken by the Canadian Hydrographic Service (CHS) in the Peel Sound/Barrow Strait region. In 1990, the CHS is planning to undertake detailed surveys of Dolphin and Union Strait utilizing the CSS. J.P. Tulley, In 1991, the CHS plan to continue the surveys eastward where ice conditions permit through the Southern Route (personal communications Mr. Jake Kean, CHS, October 24, 1988).

Victoria Strait and M'Clintock Channel are generally covered with ice year-round and this often prevents survey vessels from being deployed to the region for the execution of controlled surveys. The future refinement of "through the ice" depth charting systems may greatly improve the acquisition of accurate depth soundings for these ice-infested areas.

The Southern Route of the North-West Passage via Victoria Strait has not been completely or accurately surveyed (by controlled surveys) when compared to other charted waters of the Canadian Arctic Archipelago (ie. Lancaster Sound, Barrow Strait and the Beaufort Sea). The majority of charted depths in the Southern Route were obtained from reconnaissance track soundings and spot soundings collected by CHS vessels and by Canadian Coast Guard icebreakers during passages through the region (Sailing Directions - Arctic Canada, Volume I, CHS 1982). The land features and shoal areas are known to be subject to errors of positioning on the current charts. Positions taken off shorelines may be out by up to 7 cables (0.7 nautical miles) due to errors in the old North American datum upon which the charts were based (personal communication - Mr. Jake Kean, CHS, October 24, 1988).

The current chart grids are based on a different datum when compared to the presently available satellite navigation system grid utilized onboard modern vessels. The current chart grids will be different again from the upcoming Global Positioning System (GPS) satellite grid. The required controlled survey of this route will take decades to complete, at the present rate of progress, and only upon completion of the work will truly accurate charts be available. Until such time, vessels transitting the Southern Route must accept the risk of encountering uncharted obstructions, and deeper draft vessels will be at greater risk.

The figures (A-1 to A-10) in Appendix A delineate the boundaries of the deep-draft corridor as identified by a Canarctic Master Mariner under this task. The investigator consulted all of the available charts for the Southern Route and chose the vessel routing which provided maximum navigator confidence in terms of bathymetry and positioning capabilities.

The general conclusion of this exercise also identified a requirement for detailed controlled bathymetric surveys throughout the region before regular commercial traffic by deep-draft vessels is initiated. The most hazardous area identified on currently available charts exists to the east of Jenny Lind Island in Victoria Strait where a number of shoals have been identified during historical transits by Canadian Coast Guard icebreakers. The preferred deep draft corridor lies to the west of Jenny Lind Island in a channel which does not contain identified shoals.

Figure 5 is a generalized isobath map for Larsen Sound and Victoria Strait which was produced from an analysis of CHS nautical charts. The significant features in this figure

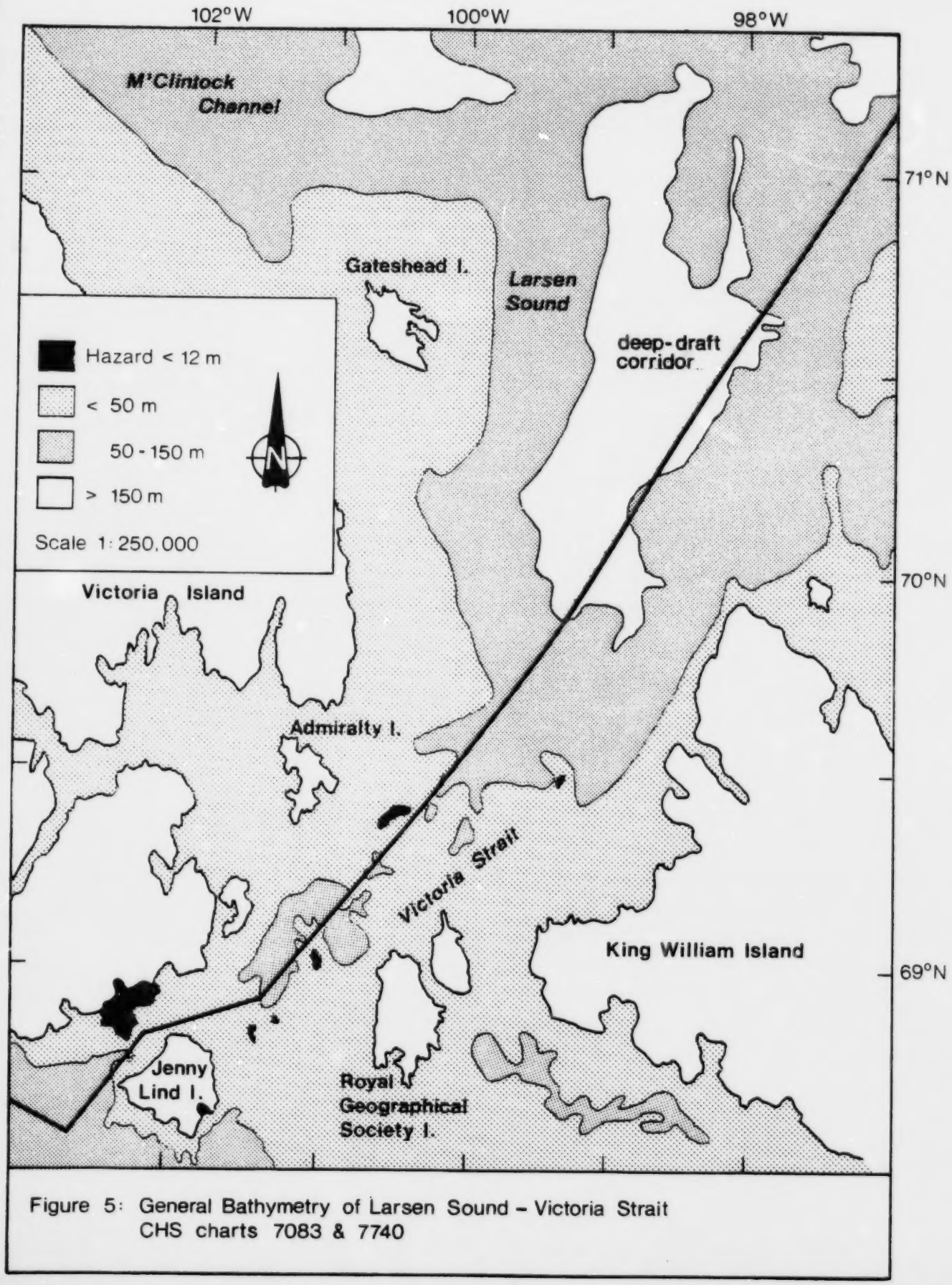

Figure 5: General Bathymetry of Larsen Sound – Victoria Strait
CHS charts 7083 & 7740

include: 1) the deep basin in Larsen Sound with soundings at a depth greater than 50 metres and areas over 150 metres, 2) the shallow areas of Victoria Strait, with soundings of less than 50 metres, and 3) the deeper soundings to the south and west of Jenny Lind Island.

The deep basin in Larsen Sound is known to receive sea ice from M'Clintock Channel during the break-up season. The availability of adequate bathymetry allows for vessels to navigate around detected sea ice hazards in this region.

Victoria Strait is characterized by charted depths of 50 metres or less. A geological arch trends through the region connecting King William Island to the Collinson Peninsula of Victoria Island. This resistant geological structure includes the Royal Geographical Society Islands, Jenny Lind Island, Admiralty Island, Gateshead Island and numerous other un-named islands and shoals. Several charted shoals of concern to operators of any vessel have been identified in Victoria Strait (Appendix A-5). A controlled regional survey in the area would assist to accurately define the extent of navigable waters available to deep-draft vessels. The identification of shoals east of Jenny Lind Island, and the paucity of soundings in this waterway precludes this routing option as a reliable deep-draft corridor. A preferred deep-draft corridor exists in Icebreaker Channel, between Victoria Island and the west coast of Jenny Lind Island (Appendix A-5). Deeper water exists to the south of Jenny Lind Island and extends across northern Queen Maud Gulf to the eastern entrance to Dease Strait.

Another area containing reported shoals includes the area north of Cape Alexander (Kent Peninsula) in Dease Strait (Appendix A-7) and in the Cache Point Channel region of Dolphin and Union Strait (Appendix A-9). In both regions the current

density of soundings provides a reliable deep-draft corridor in which vessels may avoid charted shoals however a more controlled survey would delimit the breadth of the deep-draft corridor.

2.2 Aids to Navigation (NAVAIDS)

There are several racons, beacons and passive reflectors positioned and maintained at strategic locations along the Southern Route of the North-West Passage. The majority of the transits through the region have taken place under good visibility conditions and by vessels of medium to light draft. Within this task a Canarctic Master Mariner evaluated the positions and types of NAVAIDS presently available to navigators attempting passage through the region. The evaluation focused on the suitability of utilizing the existing NAVAIDS to assist in position fixing along the entire deep-draft corridor. As a result of this evaluation a number of new NAVAIDS were proposed in order to improve the positioning of a deep-draft vessel in selected areas. The proposed new NAVAIDS are presented in Table 3.

The Radar Laboratory at McMaster University has developed and tested passive cross-polarized reflectors for use with the cross-polarized ice radar developed for vessels operating in ice infested waters. This system has shown great promise in providing reliable fixes to navigators in areas where accurate positioning is required to avoid charted hazards. Offshore Surveys Limited of Vancouver has developed a positioning system utilizing similar passive radar reflectors and onboard processing of radars information to accurately position a ship. Upon being successfully tested and approved these new cross-polarized reflector systems should be well suited to applications along the deep-draft corridor which is characterized by low shorelines and inaccurately charted coastlines.

Table 3

Proposed new Aids to Navigation (NAVAIDS) for the Southern Route of the North-West Passage

Location	Position	Existing Navaid	Proposed Navaid
For Ice Breaker Channel			
De Haven Point Victoria Island	69°00'N 101°46'W	None	Beacon with Radar Reflector
north western Jenny Lind Island	68°49'N 102°00'W	None	Racon
for Southern Victoria Strait (east of Jenny Lind Island)			
Victoria Strait western Scott Keltie Island	69°05'N 100°26'W	None	Radar Reflector
for Cache Point Channel - Dolphin and Union Strait			
northeastern Douglas Island	68°28'N 113°28'W	Beacon	Racon

3.0 Historical Vessel Transits

The Southern Route of the North-West Passage has been used historically by numerous vessels of varying drafts (drawing 7-8 metres max.), however deeper draft vessels (drawing up to 12 metres) have not transitted the region to date.

The Northern Route of the North-West Passage is the most direct route to Tuktoyaktuk from Resolute Bay, (800 n.mi versus 1200 n.mi through the Southern Route). The Northern Route also offers significantly more favourable bathymetric conditions to operators of deep-draft vessels. However, historical ice climatology studies focussed on the Northern Route have indicated the persistance of difficult ice conditions year-round, particularly in the western Viscount Melville Sound/eastern M'Clure Strait region (Canarctic, 1986 Tp-7542-E). The Western Parry Channel Ice Regime Study using information available up to 1986, investigated the passage experience of icebreaking vessels which have transited the Northern Route of the North-West Passage. All of the historical transits have been accomplished during the summer and several voyages were hampered by encounters with high concentrations of old ice. Ice conditions in the Northern Route deteriorate rapidly in the early winter period with the build-up of a heavily ridged old ice/first year matrix in between the substantial old ice floes. The prospects for undertaking winter transits through the Northern Route, except under unusually light ice conditions, would appear feasible for high ice class vessels upon review of the historical data base of winter ice conditions.

To date, a significantly greater number of vessels of varying drafts and displacements have completed full transits of the Southern Route of the North-West Passage. This total can be supplemented by the numerous partial transits of Canadian Coast

Guard icebreakers and supply vessels, which either assisted vessels in distress in the region, undertook bathymetric surveys or delivered cargoes to the scattered settlements located along the Southern Route. In this section the significant historical vessel transits through the Southern Route will be reviewed in association with selected comments advanced by Masters of vessels which have transitted the deep-draft corridor of the Southern Route.

3.1 Vessel Transits of the Deep-Draft Corridor (Southern Route)

The first complete transit of the Southern Route was accomplished by Roald Amundsen in the vessel "GJOA" between 1903-1906. The route selected did not include a transit of Victoria Strait but rather the vessel exploited the shallow-draft route to the east of King William Island through James Ross Strait and Simpson Strait. The vessel spent successive winters at Gjoa Haven and King Point. The first vessel to negotiate the deep-draft corridor of the Southern Route was the CCGS John A. MacDONALD in 1967.

A full transit of the North-West Passage commonly refers to a passage which extends from Lancaster Sound to the Chukchi Sea (or the reverse case). Partial transits refer to passages which only cover a part of the distance across the top of the North-American continent.

This study focussed on the accessibility of the Beaufort Sea from the east via the deep-draft corridor of the Southern Route of the North-West Passage. Vessel movements which exploited the deep-draft corridor through Victoria Strait were considered of special interest to this study and are summarized in Table 4. This information was extracted from a listing of all North-West

Table 4

Historical Vessel Transits through the Southern Route (Deep Draft Corridor) of the North-West passage.

Year	Vessel	Direction	Comments
1967	CCGS JOHN A. MacDONALD	West bound	First transit of the deep water route
1969	USCG NORTHWIND	East bound	Intended to assist TS MANHATTAN, engine broke down in Viscount Melville Sound and returned to west via M'Clintock Channel and deep-water corridor of Southern Route
1975	PANDORA II THETA	East bound	Institute of Ocean Sciences (DFO) Oceanographic work
1975	CCGS JOHN A. MacDONALD	West bound East bound	deployed off Hershel Island to assist CCGS CAMSELL and commerical dredge BEAVER MACKENZIE - damaged and beset by ice, return passage through same route
1976	CCGS LOUIS S. ST. LAURENT	Partial transit	escorted the CANMAR EXPLORER II to Queen Maud Gulf (open water) then returned to the east.
1976	CANMAR EXPLORER II	West bound	escorted by CCGS LOUIS S. ST. LAURENT as far as Queen Maud Gulf then proceeded to Beaufort Sea.
1976	CCGS J.E. BERNIER	East bound	escorted by the CCGS LOUIS S. ST. LAURENT.

Table 4 (con't)

Historical Vessel Transits through the Southern Route (Deep Draft Corridor) of the North-West passage.

Year	Vessel	Direction	Comments
1977	CCS BAFFIN	Partial transit	damaged bow while undertaking survey work in Victoria Strait.
1978	CCS HUDSON	West bound	completed bathymetric surveys
1981	CCS HUDSON	East bound	transit part of circumnaviation of the North-American continent.
1983	ARCTIC SHIKO	East bound	ATL Vessel delivered to Atlantic Coast
1985	ARCTIC HELIOS	West bound	
1985	ARCTIC MALLIK	East bound West bound	ATL vessel transit to Resolute Bay
1985	CCGS JOHN A. MacDONALD	West bound East bound	deployed to assist the CCGS CAMSELL
1988	CCGS HENRY LARSEN	East bound	maiden voyage
1988	CCGS MARTHA L. BLACK	East bound	damaged propellers escorted by CCGS PIERRE RADISSON
1988	CCGS PIERRE RADISSON	West bound East bound	deployed to assist CCGS MARTHA L. BLACK
1988	USCG POLAR STAR	East bound	returned to east in company of the CCGS MARTHA L. BLACK
1988	M/V SOCIETY EXPLORER	East bound	commercial passenger cruise

Table 4 (con't)

Historical Vessel Transits through the Southern Route (Deep Draft Corridor) of the North-West passage.

Year	Vessel	Direction	Comments
1988	CCGS JOHN A. MacDONALD	West bound East bound	deployed to provide logistical support to USCG POLAR STAR.

Passage transits compiled by Canadian Coast Guard (CCGN, 1989).

A total of 24 transits were completed through the deep-draft corridor between 1967 and the end of the 1988 shipping season. A majority of these transits were accomplished by Canadian Coast Guard icebreakers, although the route has also been exploited by United States Coast Guard icebreakers, survey vessels, arctic tugs, cruise ships and a drill ship.

The majority of historical transits were undertaken during the August-September time frame under good visibility and light ice conditions. Very little documentation was found in the historical archives regarding these transits. Ship's navigation logs and ice conditions reported in A.E.S. observed ice charts were the only records of the ice conditions encountered during historical transits. In instances where a vessel encountered ice pressure (most commonly in the Victoria Strait region) no significant documentation of ice and environment conditions was undertaken in order to define events which caused the vessel to become entrapped in the converging ice field. These data are crucial to advancing an understanding of regional ice climatology. The detailed documentation of ice transits could inevitably assist navigators in avoiding onerous ice conditions during future transits through the region.

During the maiden voyage of the CCGS HENRY LARSEN in 1988 conditions encountered along the passage were documented and compiled in an internal report (Wartsila Marine Inc., 1988). No serious ice conditions were reported during the transit through the Southern Route. The post voyage report provided a detailed description of the ice conditions encountered for performance testing of the ship in Viscount Melville Sound (Northern Route of the North-West Passage).

3.2 Comments of Canadian Masters with Experience in the Southern Route

As a component of the historical transits review task a Canarctic Master Mariner interviewed several Canadian Masters who have commanded vessels through the deep-draft corridor of the Southern Route. This effort was directed at soliciting comments from these experienced navigators regarding their historical passages through the region. The navigators interviewed included:

Captain P. Fournier - Canadian Coast Guard (retired)
Captain G. Burdock - Canadian Coast Guard (retired)
Captain F. Mauger - Bedford Institute of Oceanography (retired)
Captain S. Gomes - Canadian Coast Guard (Master - CCGS HENRY LARSEN)
Captain G. Barry - Canadian Coast Guard (Master - CCGS JOHN A. MACDONALD)

3.2.1 Captain P. Fournier

Captain Fournier commanded the CCGS JOHN A. MacDONALD on the first transit of the deep-draft corridor. The vessel was deployed to assist vessels in the western Arctic in September 1967. No soundings existed for the Southern Route by this date and there were no aids to navigation along the passage route. The route was selected on the basis of depth sounding trends and the "lay of the land". It was quite fortunate that no submerged hazards were encountered in southern Larsen Sound and northern Victoria Strait during the transit and the ice encountered in these waterways was not judged to be onerous. The remainder of the passage through Queen Maud Gulf, Dease Strait, Coronation Gulf and Dolphin and Union Strait was accomplished in open water.

In 1976 Captain Fournier commanded the CCGS LOUIS S. ST. LAURENT in the Victoria Strait area for most of September. In early September assistance was provided to the drill ship EXPLORER II which was enroute to the Beaufort Sea from the east. The CCGS LOUIS S. ST. LAURENT did not experience difficulties however, the drill ship became beset in first-year and old ice, under pressure, east of Admiralty Island (69°30'N - 100°00W) for over 2 days. The CCG icebreaker was re-deployed to the east once the drill ship had cleared Jenny Lind Island.

In late September the CCGS LOUIS S. ST. LAURENT returned to Victoria Strait to assist the CCGS BERNIER. The extensive mixed ice conditions in the strait had persisted since earlier in September and pressure events had reduced the eastward progress of the CCGS BERNIER. By contrast the CCGS LOUIS S. ST. LAURENT was not significantly hindered at this time by the ice conditions in the Victoria Strait area.

3.2.2 Captain G. Burdock

Captain Burdock commanded the CCGS JOHN A. MacDONALD into Peel Sound from Foxe Basin, Fury & Hecla Strait and Bellot Strait in September, 1968. Light new ice was encountered throughout Larsen Sound and Victoria Strait as the icebreaker circumnavigated Jenny Lind Island undertaking survey work.

The vessel went aground on the shoal east of Jenny Lind Island (68°45'N 101°25'W) which is currently identified on CHS chart #7083 (Appendix A-5). The vessel exited the Southern Route to the east in November.

In August 1977 Captain Burdock and the CCGS LOUIS S. ST. LAURENT escorted the CCS BAFFIN from Bellot Strait to Jenny Lind Island. Heavy concentrations of decaying first-year ice were

encountered in northern Victoria Strait and this ice was under occasional pressure.

Assistance was provided to the CCGS CAMSELL and on occasion the CCGS CAMSELL couldn't follow astern of the CCGS LOUIS S. ST. LAURENT. The CSS BAFFIN was escorted out of the Southern Route to the east in early September.

3.2.3 Captain F. Mauger

In 1977 Captain Mauger commanded the CCS BAFFIN to the Cambridge Bay area returning to the east. The CSS BAFFIN was deployed into Peel Sound from Bellot Strait and the following post-voyage account by Captain Mauger was published in the Sailing Directions - Arctic Canada (Canadian Hydrographic Service, 1985 p.49)

> "In 1977 the survey ship BAFFIN entered Bellot Strait from the east at 0715 Eastern Standard Time on August 6, approximately two hours after low water at Fort Ross. A localized 7 to 8 knot current was encountered which was flowing westerly on the north side of the strait and there was an equally strong flow in an easterly direction on the south side. There were numerous whirlpools throughout the Magpie Rock area from shore to shore. The current slackened somewhat 0.8 mile west of Magpie Rock.
>
> A reconnaissance flight by the ship's helicopter at 0400 had reported mostly open water throughout the strait with a few small patches of ice. Three hours later when BAFFIN entered the strait there was 9/10 coverage of second-year and multi-year ice. About 0.6 mile east of Halfway Island, BAFFIN encountered 10/10 multi-year ice under very strong pressure.
>
> BAFFIN became beset in ice 2 miles east of Halfway Island at 0745 and required full engine power to hold her position. Very little forward movement was made until 1000,

> at which time the tidal flow reversed thus relieving the pressure. BAFFIN reached the western end of Bellot Strait at 1200.
>
> From this experience it appears that ice reports cannot be relied on unless they are less than thirty minutes old, as a BAFFIN reconnaissance flight four hours before entering the strait, and reports from Ice Forecasting Central, Ottawa, had indicated ice-free conditions throughout. The direction of the current is very erratic and a ship that was underpowered would in all probability find herself in great difficulty.

It was recommended that mariners should exercise extreme caution in this area. As a result of this type of experience Bellot Strait is not suggested as the main access to southern Peel Sound for deep-draft vessels attempting a transit of the Southern Route of the North-West Passage. However, Bellot Strait could become an alternate entry into the Southern Route should northern Peel Sound become congested with dangerous ice in certain years. A vessel should not preceed through this alternate waterway unless current ice information indicates favourable conditions.

After the passage through Bellot Strait, the 1977 transit of the CCS BAFFIN continued under escort by the CCGS LOUIS S. ST. LAURENT, through heavy first- year ice, to the Jenny Lind Island area. The CGS BAFFIN incurred damage to her bow while in pressured ice in Victoria Strait and was subsequently escorted eastward by the CCGS LOUIS S. ST. LAURENT and CCGS D'IBERVILLE.

Captain Mauger returned to the Southern Route in 1978 and 1981 in command of the CSS HUDSON. In early September 1978 the CGS HUDSON transitted from east to west to undertake survey work. In contrast to 1977, only traces of old ice were encountered during the transit. In mid-September, 1981 the CSS HUDSON transitted the deep-draft corridor from west to east in open

water conditions.

Captain Mauger had never transitted Icebreaker Channel although he had initially been tasked to survey this waterway in 1977. Damage to the bow of the CSS BAFFIN that year precluded undertaking this survey work.

3.2.4 Captain S. Gomes

Captain Gomes sailed as the mate onboard the CCGS JOHN A. MacDONALD through the Southern Route in November 1968. His first command of a vessel through the deep-draft corridor of the Southern Route occurred onboard the CCGS HENRY LARSEN on her maiden voyage in August 1988.

In 1988, CCGS HENRY LARSEN encountered open water conditions along the Southern Route from Cache Point Channel in Dolphin and Union Strait to Victoria Strait. A helicopter reconnaissance mission flown in the region identified high concentrations of old ice in M'Clintock Channel and western Larsen Sound. The vessel proceeded at slow speed into eastern Larsen Sound and accessed the west coast of the Boothia Peninsula for the dedication of a plaque comemorating the passage through the area in the 1940's by the RCMP vessel ST. ROCH under the command of Sargent Henry Larsen. Although shallow bathymetry had been identified on the CHS charts for the eastern Larsen Sound area, no shoals were encountered and only decayed first-year ice conditions were experienced.

Captain Gomes recommended that radar reflectors be installed on the western and north-western corners of Jenny Lind Island to assist vessels in positioning themselves in Icebreaker Channel. Because of the presence of shoals off the east coast of Jenny Lind Island Captain Gomes did not recommend this route to be used

by deep-draft vessels unless ice conditions reported in Icebreaker Channel were considered more severe.

3.2.5 Captain G. Barry

Captain Barry commanded the CCGS JOHN A. MacDONALD westbound into Amundsen Gulf in late September 1985. The transit was undertaken to assist the CCGS CAMSELL. No signficant ice was encountered in Peel Sound or Larsen Sound however numerous course alterations were required in Victoria Strait to avoid scattered old ice floes. Some ice pressure was experienced in Amundsen Gulf before returning eastward along the same route.

Captain Barry reported that the existing soundings in all areas were accurate and the available radar beacons were well positioned for the fixing of positions in the constricted waterways. M'Clintock Channel was considered for the transit in 1985 however the heavy old ice conditions observed during aerial reconnaissance missions precluded any attempted passage. The deep-draft corridor through Cache Point Channel presented no problems during Captain Barry's transits. The soundings were considered accurate, the radar beacons well positioned and the transit of Dolphin and Union Strait was accomplished under dark conditions.

In late August 1988 Captain Barry commanded the CCGS JOHN A. MacDONALD on a return trip from Resolute to the Beaufort Sea. The trip was undertaken to escort the USCG POLAR STAR eastward through the Southern Route. Decayed first-year ice was encountered in Victoria Strait and only strips of first-year ice were encountered in the waterways south of Victoria Island. During the September transit to the east the vessel encountered predominantly open water conditions.

4.0 Ice Climatology of the Southern Route

Access to the waterways of the Canadian Arctic for shipping are presently regulated under the Arctic Shipping Pollution Prevention Regulations (ASSPR). Shipping Safety Control Zones were established in 1972 in recognition of the differences in ice conditions throughout the various waterways of the Canadian Arctic. It was decided that Arctic Class vessels would only be permitted to enter control zones during time periods when ice conditions were deemed of negligible consequence to the structural integrity of the vessel. The control zones were defined and established at that time on the basis of the ice climatology expertise available in early 1970's. More baseline information has been learned in the interim regarding the inter-seasonal variablity of ice conditions throughout the Arctic.

Updated ASPPR regulations are presently under investigation and revision to introduce flexibilty to the existing zone date entry system for controlling shipping activity in the Canadian Arctic. The proposed system is based on identifiable ice regimes which are weighted for each category of vessel. To be applied, the proposed new system would require superior ice information and the recognition of the impact of various defined ice conditions on the safety and performance of classed vessels.

Presently, in order to complete a passage through the Southern Route, a vessel must transit all or parts of control Zones 2,6,7 and 11 (Canadian Hydrographic Service, 1982 p.100). Table 5 lists the permissible shipping windows for Arctic Class 4 vessels attempting access to the control zones of the Southern Routes under the existing regulation.

Zone 2 is the most restrictive control zone in acknowledgement of M'Clintock Channel's reputation as an "ice-

Table 5

Shipping Window for Arctic Class 4 vessel under the existing ASPPR Regulations (Canadian Hydrographic Service, 1982, p.107)

CASPPR Zone	Waterways	Entry Date	Exit Date
2	M'Clintock Channel	August 15	October 15
6	Peel Sound - Franklin Strait	July 20	December 31
7	Victoria Strait - Queen Maud Gulf	July 15	January 15
11	Dease Strait - Coronation Gulf - Dolphin and Union Strait - Amundsen Gulf	July 5	January 15

sink" for the perennially exported old ice concentrations from Viscount Melville Sound. The brief access window for a Class 4 vessel (Aug. 15-Oct.15) corresponds to the period of maximum break-up and ice clearing in the region. However, this zone is seldom if ever considered by vessel operators when attempting a transit of the Southern Route. The remaining control zones (6,7, and 11) have longer access windows which generally extend from mid-July to early January. This extended shipping season for Class 4 vessels recognizes the existance of a first-year ice cover which predominates throughout the majority of the waterways within these control zones.

Under the existing regulations type D vessels are not permitted entry to Control Zone 6 at any time of the year. By contrast the operator of an Arctic class 7 vessel would be permitted year-round access to the deep-draft corridor of the Southern Route. The existing ASPPR regulations do not recognize the possibility of encountering difficult ice conditions within a particular vessel's access window. The existing regulations also do not address the possibility of favourable conditions existing outside of a particular vessel's access window.

Ice climatology studies will inevitably assist in the revision of ASPPR and improve a general understanding of the distribution, composition and movement of sea ice in Canadian sovereign waters. Investigations of the timing of break-up, physical ice properties and sea ice pressure events, from detailed and accurate ice information sources, will significantly assist marine operators by improving the recognition and exploitation of favourable ice conditions.

4.1 Previous Studies

The ice climatology of the Southern Route of the North-West Passage has been investigated superficially when compared to the more comprehensive studies which have been executed for the waterways of the Parry Channel and the Beaufort Sea.

Historical ice conditions in the Canadian Arctic have been compiled and presented in several ice atlases (Lindsay, 1975, 1977a, 1977b, 1981), (Markham, 1981) and (Canarctic, 1987). Lindsay's atlases presented ice information recorded during routine reconnaissance flights by the Polar Continental Shelf Project from 1961-1978. Markham's ice atlas presented a synthesis of satellite remote sensing and AES observation, in a mapped format, representing the median summer ice conditions for the arctic waterways of the Canadian Arctic.

Although numerous reports and analyses of the summer break-up were published from 1963-1973 there was insufficient data upon which to produce reliable average conditions. Markhams's ice atlas was produced by reviewing fifteen years of ice data collected by trained ice observers and ice forecasters. The information sources utilized by AES Ice Forecasters included: aerial and shipboard observations and satellite and airborne (Side Looking Airborne Radar - SLAR) remote sensing information. The median ice conditions mapped can be considered of general interest to ship operators, resource industries and planners of northern development. However, detailed ice climatology studies are required to highlight the range of ice conditions which can be expected in defined regions throughout the year, and the environmental causes of major changes in the distribution of sea ice in navigable waterways.

In 1986 Canarctic Shipping Company Limited and the Canadian Coast Guard initiated the collection and analysis of detailed synthetic aperature radar (SAR) data of winter conditions in the Canadian Arctic. Under the program SAR data have been collected over three consecutive winters (1986/87 to 1989/90) and presented in the Canadian Arctic Marine Ice Atlas (Canarctic, 1987, (Canarctic, in progress). Further collection of ground truthed SAR data sets representing year-round ice conditions will be required for every possible arctic shipping corridor in a continuing effort to assess the feasibility of developing year-round Arctic shipping scenarios.

The Expanded Ice Services Program at AES - Ice Branch, scheduled to come on line in 1989, will include the routine collection of SAR data in the Canadian Arctic. The year-round collection of highly detailed data sets such as SAR should vastly improve the knowledge base on ice-conditions in the North-West Passage.

The Sailing Directions - Arctic Canada Volume I (CHS 1982) contains the only general descriptions of the ice conditions commonly encountered in the waterways of the Southern Route. The following descriptions were paraphrased from these environmental overviews.

4.1.1 Peel Sound and Franklin Strait

The landfast winter ice cover in this region reaches a mean thickness of 195 cm by late spring. Clearing of ice is predominantly accomplished through in-situ ablation as the currents in these waterways are very weak and have little effect on break-up. The clearing of ice depends heavily on the warmth of the summer season and in cool years varying concentrations of old ice will survive in the region to become embedded in a

growing first-year matrix.

The ice cover becomes mobile by mid-August with clearing commonly occurring by early September. On occassion, sea ice may ingress during the open water season into these waterways from Barrow Strait or southern Franklin Strait. Freeze-up begins in mid-September and the ice cover consolidates by the end of October.

Under severe conditions a landfast ice cover, or very close pack ice concentrations, may persist in the region throughout the summer season. In unusual years the fracture and clearing of ice from these waterways may occur up to a month earlier than the norm. Freeze-up may also begin up to a month later in the fall in unusual years.

4.1.2 M'Clintock Channel, Larsen Sound and Victoria Strait

M'Clintock Channel has traditionally been termed the "ice-sink" for the western part of the Parry Channel. M'Clintock Channel has a broad access to south-eastern Viscount Melville Sound and substantial quantities of ice appear to drift southward into M'Clintock Channel in the late summer period under the influence of the prevailing winds. This time period also corresponds to the timing of maximum ice mobility in the Western Parry Channel. The intruding ice is predominantely second-year and multi-year ice producing heavy accumulations of compacted old ice throughout M'Clintock Channel especially south and west of Gateshead Island. This island forms a partial obstruction to the movement of sea ice eastward into Larsen Sound and Victoria Strait.

The Southern Route region experiences less severe climatic conditions in comparison to conditions reported in the northern regions of the Arctic Archipelago. As a result there is continual ablation and wastage of the old ice during the summer period thus preventing excessive ice congestion in most years and facilitating the formation of a first-year ice matrix between the old ice floes.

Surface melt begins with the formation of surface puddles in mid-June, however, extensive break-up of the ice cover does not commonly occur until early August. Fracturing begins in Victoria Strait and James Ross Strait spreading northward into M'Clintock Channel.

Light winds predominate in the region during most seasons, however strong winds may drive the pack ice down wind, destroying rotten ice and creating extensive shore leads on the opposite side of the channel. Easterly winds in late August and September can lead to the development of heavy old ice concentrations along the Victoria Island coast and the clearing of Larsen Sound and the west coast of Prince of Wales Island. Subsequent to such an event, freeze-up in September will form large expanses of predominantly first-year ice in Larsen Sound which can be prone to early break-up during the following summer.

Persistent north-westerly winds in August can cause congestion in James Ross Strait and Victoria Strait which is possibly responsible for the legendary persistence of the ice cover to break up in these waterways during the summer.

4.1.3 Queen Maud Gulf

There is a southward drift of cold water into Queen Maud Gulf from Victoria Strait. As a result, thicker floes may on

occasion accumulate in this waterway in comparison to the other waterways in the approaches to Amundsen Gulf. The numerous islands, islets and shoals between King William Island and Victoria Island prevent the large scale transport of old ice floes into Queen Maud Gulf. The invading ice tends to occur in strips and patches. Occasional intrusions of old ice from M'Clintock Channel, Larsen Sound and Victoria Strait may occur during the shipping season and an average of 1/10 old ice is commonly embedded in the first-year ice matrix during the winter.

Surface melt accelerates by mid-June with break-up beginning in late-July during normal years. Clearing of ice progresses in early August from Simpson Strait in the east, and Dease Strait in the west, with the pack reduced to scattered patches by late August. By this time of the year, ice floe mobility to the north in Victoria Strait can result in the influx of the ice into Queen Maud Gulf, particularly under the influence of strong northerly winds.

Freeze-up in the area does not begin until early October as a result of the warmer regional climate in contrast to conditions in the more northerly waterways.

4.1.4 Dease Strait and Coronation Gulf

The presence of numerous chains of islets in these waterways ensures the persistence of a landfast ice cover throughout the winter. Break-up develops from the west to the east as a result of in-situ ablation assisted by fresh water run-off from the Coppermine River. The commonly level ice cover develops extensive surface ponding with the acceleration of warming conditions leading to fracturing by early July. Disintegration of the ice cover occurs rapidly in Coronation Gulf. Ice-free conditions are commonly reported by late July. Dease Strait

does not clear of ice until early August and ice-free conditions prevail in both waterways throughout August and September. On rare occasions old ice from Queen Maud Gulf can penetrate Dease Strait. Similarly, polar pack ice can, on occasion, penetrate western Coronation Gulf from Dolphin and Union Strait and Amundsen Gulf. These are extremely unusual events dependent on the timing and extent of break-up and the occurrence of suitable winds at the appropriate season. Freeze-up begins in mid-October and the ice cover commonly consolidates in normal years in November.

4.1.5 Dolphin and Union Strait and Amundsen Gulf

Tidal streams in Dolphin and Union Strait usually produce a developing polynya in June. This polynya, centered off Cape Krusenstern, expands slowly and has a minimal effect on the fracture of the ice cover. Fracturing initiates in the strait in early July with clearing of ice occurring by the end of the month in most years.

Freeze-up begins in mid-October and a level landfast ice cover is commonly present in Dolphin and Union Strait by the end of November.

By contrast, the ice pack in Amundsen Gulf remains mobile for much of the winter with consolidation occurring on average in March. Amundsen Gulf contains predominantly first-year ice which normally begins to fracture at the Cape Bathurst Polynya (from Cape Kellett, Banks Island to Cape Parry). During mild winters, the ice in Amundsen Gulf may remain mobile with the polynya forming further east near Cape Baring.

The ice cover in Amundsen Gulf begins ablating in early June accelerating significantly by early July. Complete clearing of

ice commonly occurs by early August. Freeze-up in Amundsen Gulf occurs in late October with the central part of the gulf achieving new ice at the very end of the month.

Table 6 presents historical ice observations collected at selected AES Meteorological Stations along the Southern Route.

4.2 Historical SAR Data 1986-89

Synthetic Aperture Radar (SAR) data sets have been collected over the waterways of the Southern Route since December 1986. Table 7 summarizes the dates of imaging and the regions covered under the various data collection programs. The summer data set collected by STAR-2 in August 1987 was imaged during ferry runs en route to the Bent Horn oil field on Cameron Island to support the M.V. Arctic. The remaining winter data sets were collected under the Canadian Arctic Marine Ice Atlas Program 1986/87 and under the Beaufort Accessibility Study - 1987/88 and 1988/89. Examples of the winter imagery are presented in the following sub-sections along with a brief description of the main ice features which would have impacted on vessel transit through consolidated winter ice conditions.

4.2.1 Winter 86/87

The SAR imagery presented in Figure 6 may also be examined in the Canadian Arctic Marine Ice Atlas - Winter 1986/87 (Canarctic, 1987). The atlas clearly displays the persistance of heavy ice accumulations throughout the waterways of the Arctic Archipelago as a result of the minimal break-up conditions (below average melting degree day accumulations) during the summer of 1986.

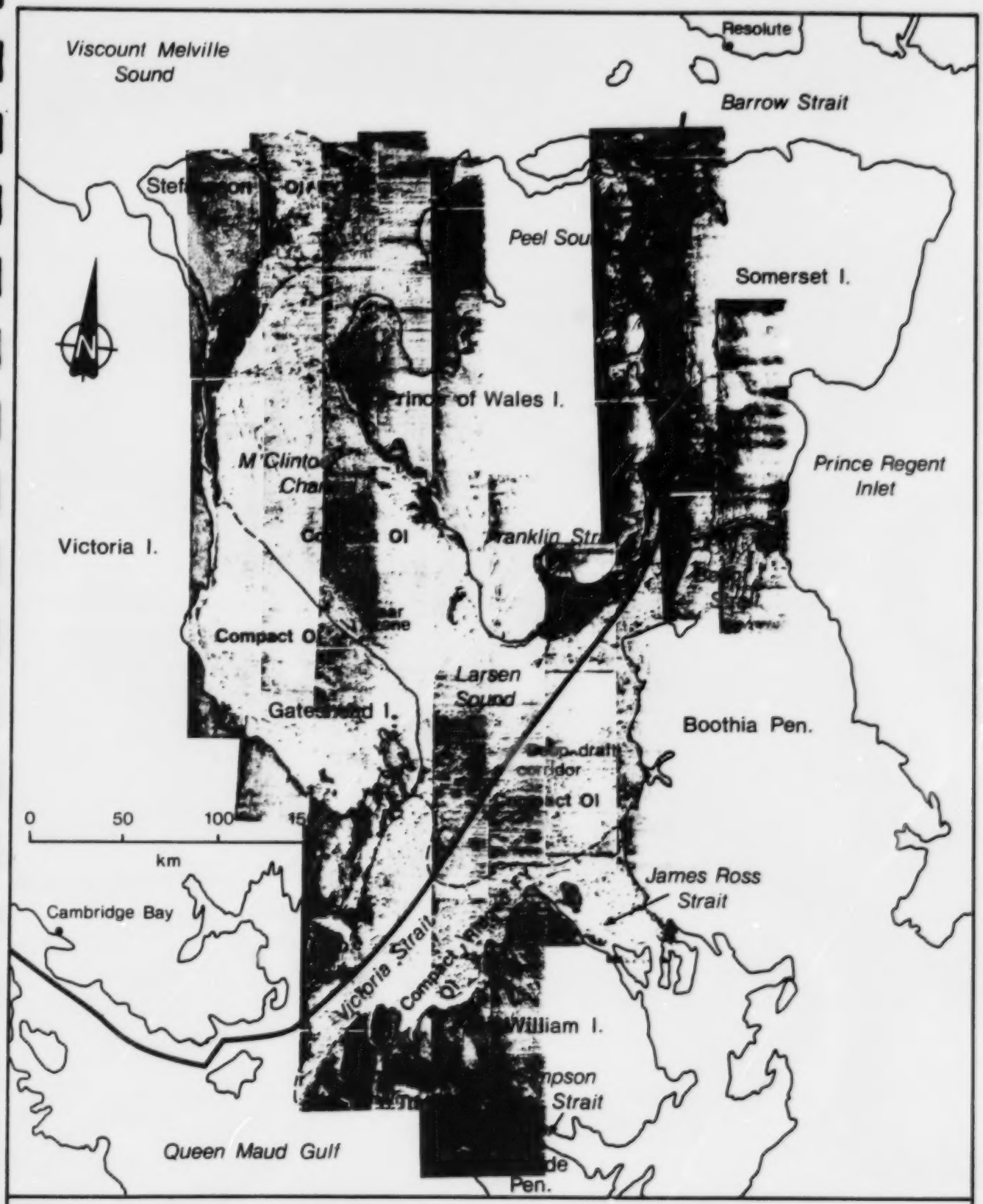

Figure 6: Distribution of Old Ice (OI) and First Year Ice (FY) - Winter 86/87 SAR mosaic of the Southern Route (STAR-1, December 1-6, 1986)

Table 6

Historical Ice Observations at AES Meteorological Stations along the Southern Route of the North-West Passage (1930-1985)

Meteorological Station	Mean date Complete Freeze Over	Mean Winter Ice Thickness (cm)	Mean date of complete Clearing of Ice
Jenny Lind Island (Queen Maud Gulf)	Nov. 02	242	Aug. 09
Cambridge Bay (Dease Strait)	Oct. 10	212	July 19
Coppermine (Coronation Gulf)	Oct. 24	185	June 19
Lady Franklin Point (Dolphin and Union Strait)	Oct. 05	176	June 29

Source: AES Ice Climatology Archive

Table 7
SAR Data Sets of the Southern Route (1986-1989)

Date	SAR System	Coverage Area (km^2)	Comments
Dec. 1-6,1986	STAR-1	265,350	early winter coverage of the waterways north of Queen Maud Gulf imaged for the Canadian Arctic Marine Ice Atlas, Winter 1986-87 (Canarctic, 1987).
Aug. 23-25,1987	STAR-2	79,200	two lines of summer data collected from Victoria Strait to northern Peel Sound during aircraft deployments to Resolute Bay in support of 1987 Bent Horn voyages.
Jan. 15-17,1988	STAR-2	293,000	mid-winter coverage of the waterways north and east (St. Roch Basin, Simpson Strait, James Ross Strait) of Queen Maud Gulf imaged for the Beaufort Accessibility Study (Phase I) and presented in the Canadian Arctic Marine Ice Altas, Winter 1987-88 (Canarctic-IP).

Table 7 (con't)
SAR Data Sets of the Southern Route (1986-1989)

Date	SAR System	Coverage Area (km)	Comments
Feb. 7-16, 1988	STAR-2	189,000	mid-winter coverage of the balance of Southern Route ice conditions (Dease Strait to Amundsen Gulf) captured for the Canadian Arctic Marine Ice Atlas, Winter 1987-1988 (Canarctic-IP).
Nov. 12-17,1988	STAR-1	278,160	early winter coverage of the waterways north of Queen Maud Gulf captured for the Beaufort Accessibility Study (Phase I).
Mar. 12-25,1989	STAR-1	199,200	late winter coverage of Victoria Strait and all waterways of the Southern Route westward to Amundsen Gulf. Captured for the Beaufort Accessibility Study (Phase I - Ice Climatology) and (Phase II - Field Validation of Winter SAR Data).

By early December 1986 Peel Sound contained light concentrations of old ice embedded in a first-year ice matrix. The old pack ice in northern Franklin Strait had blocked the western exit of Bellot Strait during the summer season as evidenced by the failed attempt of the M.V. WORLD DISCOVER to navigate into the Southern Route of the North-West Passage from Prince Regent Inlet in September 1986.

Very close pack conditions prevailed during the winter of 1986/87 in M'Clintock Channel, Larsen Sound, James Ross Strait, and northern Victoria Strait.

The old ice (bright return in the SAR mosaic) consisted of multi-year ice embedded in a second-year ice matrix. First-year ice which survives a complete summer season becomes second-year ice according to World Meteorological Organization standards on October 1st. During the winter of 1986/87 a vessel attempting transit through the Southern Route would have encountered consolidated old ice conditions from southern Franklin Strait to northern Victoria Strait (approx. 200 kilometres).

The imagery suggests that southern Victoria Strait contained lighter concentrations of old ice (small floe sizes) embedded in a deformed first-year ice matrix.

No vessels completed transits through the Southern Route of the North-West Passage in 1986 or 1987 which attests to the persistence of difficult ice conditions during these years.

4.2.2 Winter 87/88

Figure 7 highlights the regional distribution of ice in the waterways of the Southern Route in mid-January, 1988. This imagery will be presented in the Canadian Arctic Marine Ice

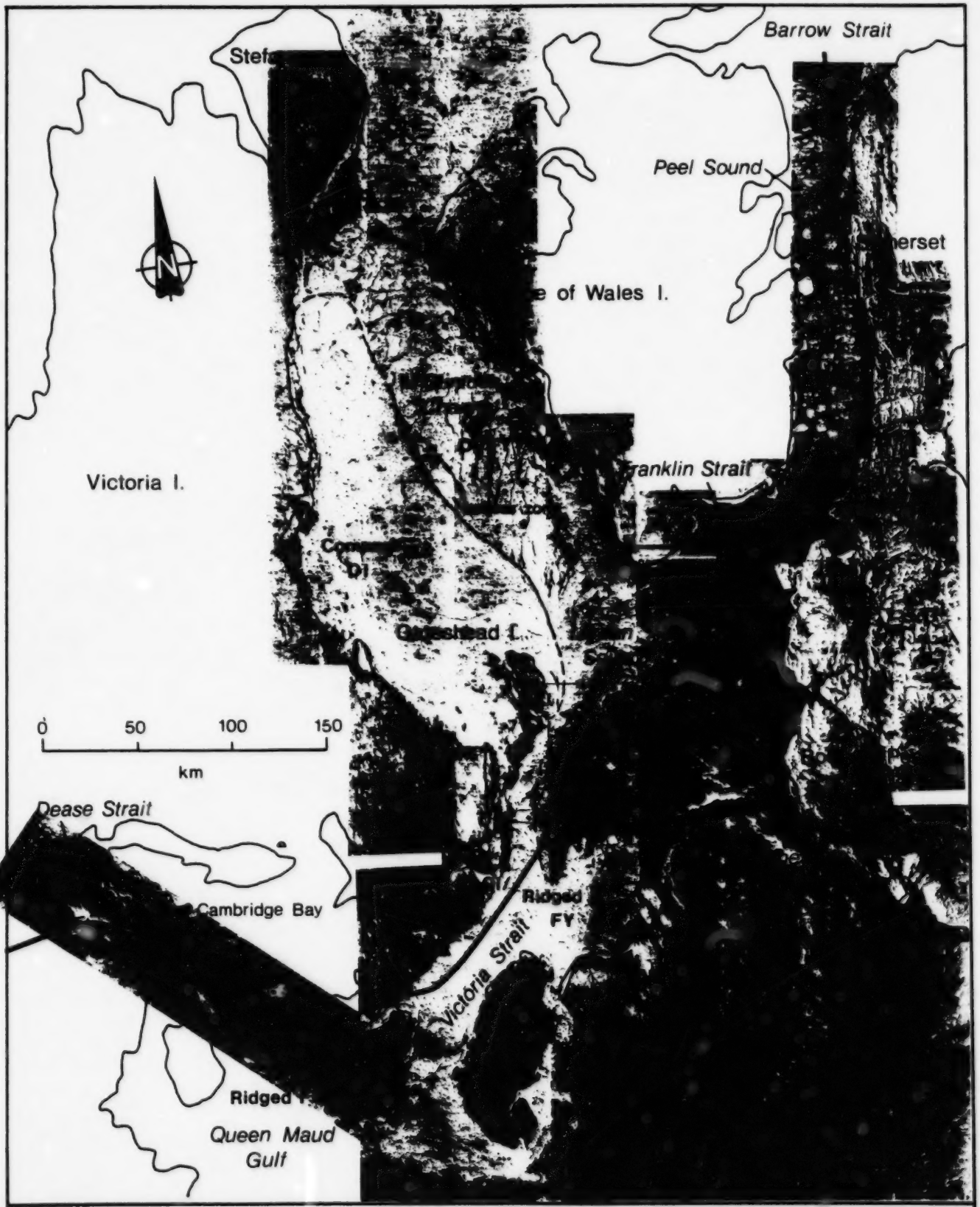

Figure 7: Distribution of Old Ice (OI) and First Year Ice (FY) - Winter 87/88
SAR mosaic of the Southern Route (STAR-2, January 15-17, 1988)

Atlas, Winter 1987/88 presently under production (Canarctic, IP). There are several salient features in this imagery which are similar to ice conditions which were interpreted from the Winter 86/87 data. Peel Sound contained 6-7 tenths concentrations of old ice in small to big floe sizes. These old ice floes entered northern Peel Sound from Barrow Strait during the summer season and consolidated during the early winter period into a level first-year ice matrix. South-western M'Clintock Channel is characterized by compact old ice conditions which do not generally clear into Larsen Sound because of the Gateshead Island barrier. This "static" old ice regime is delineated by a sharp shear zone north and northwest of Gateshead Island. During the summer of 1987, eastern M'Clintock Channel experienced moderate fracturing, and a low percentage of old ice fragments drifted along the east coast of Gateshead Island into Victoria Strait. AES Observed Ice Charts from October-November 1987 reported 4-6 tenths old ice in Victoria Strait (medium-big floes) with 5-6 tenths ridging in the first-year ice matrix. The spectral signature of the ice in Victoria Strait does not represent high old ice concentrations, but more moderate old ice concentrations surrounded by an extremely deformed first-year ice cover.

A major difference between the 1986/87 and 1987/88 winter data lies in the absence of old ice along the deep-draft corridor in Franklin Strait and Larsen Sound during the winter of 1987/88. The first-year ice cover in Larsen Sound appears heavily deformed. This is a result of continued southeasterly pressure exerted by the mobile M'Clintock Channel old ice pack on the developing young ice cover in Larsen Sound, under the combined influence of prevailing winds and currents. Franklin Strait, by contrast, contained a more level first-year ice cover partly owing to its location on the lee side of south-eastern Prince of Wales Island. Other than finding a route through the mixed ice regime of Peel Sound, a vessel attempting a winter transit of the

Southern Route in 1987/88 would have only encountered mixed old/ridged first-year ice conditions in Victoria Strait (approx. 110 kilometres). Although light first-year ridging was apparent from data collected in Dease Strait, the remainder of the transit to Amundsen Gulf would have preceeded through level first-year ice.

4.2.3 Winter 1988/89

Early winter 1988/89 ice conditions are presented in Figure 8. Air temperature values recorded at Canadian meteorological stations across the Arctic identified the summer of 1988 as an above average season characterized by high melting degree day accumulations. The old pack ice in northern and eastern M'Clintock Channel broke-up completely in 1988 leading to the export of high concentrations of old ice (big to giant floes) into Larsen Sound and northern Victoria Strait. The compact old ice regime south and west of Gateshead Island remained intact. However, a majority of the old ice in M'Clintock Channel drifted along the predominant shear zone eastward, producing a substantial barrier of old ice to navigation (approx. 90 km) along the deep-draft corridor in Larsen Sound.

Peel Sound contained very light concentrations of old ice embedded in a ridged first-year ice matrix. Franklin Strait contained predominantly smooth first-year ice and ridged first-year ice conditions prevailed in Victoria Strait.

Victoria Strait and the waterways westward to Amundsen Gulf were imaged during March 1989 to map the nature of the late-winter ice cover through this sector of the Southern Route. The SAR data collected during the March, 1989 data acquisition program are presented in Figure 9.

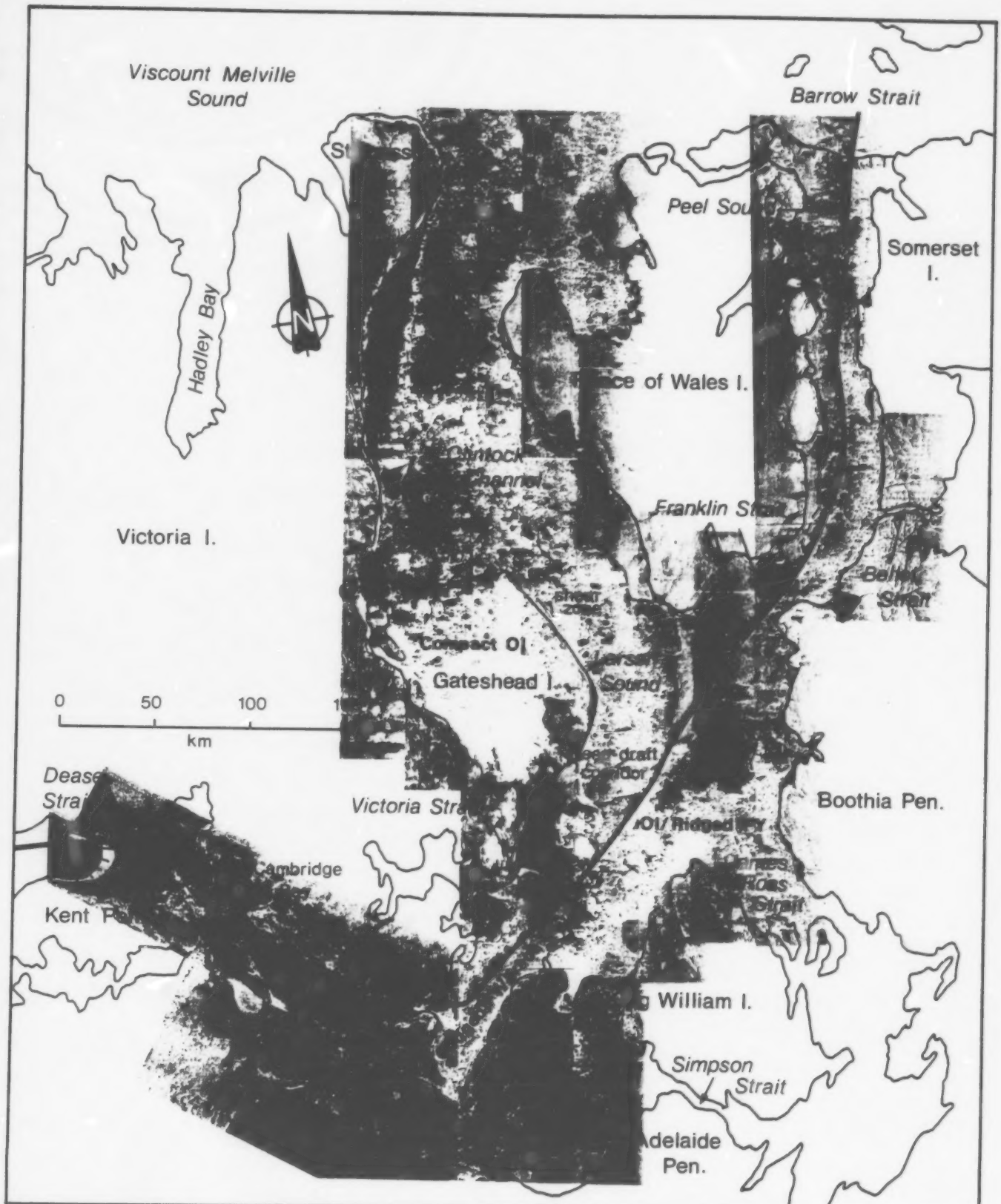

Figure 8: Distribution of Old Ice (OI) and First Year Ice (FY) - Winter 88/89
SAR mosaic of Southern Route (STAR-1, November 12 - 17, 1988)

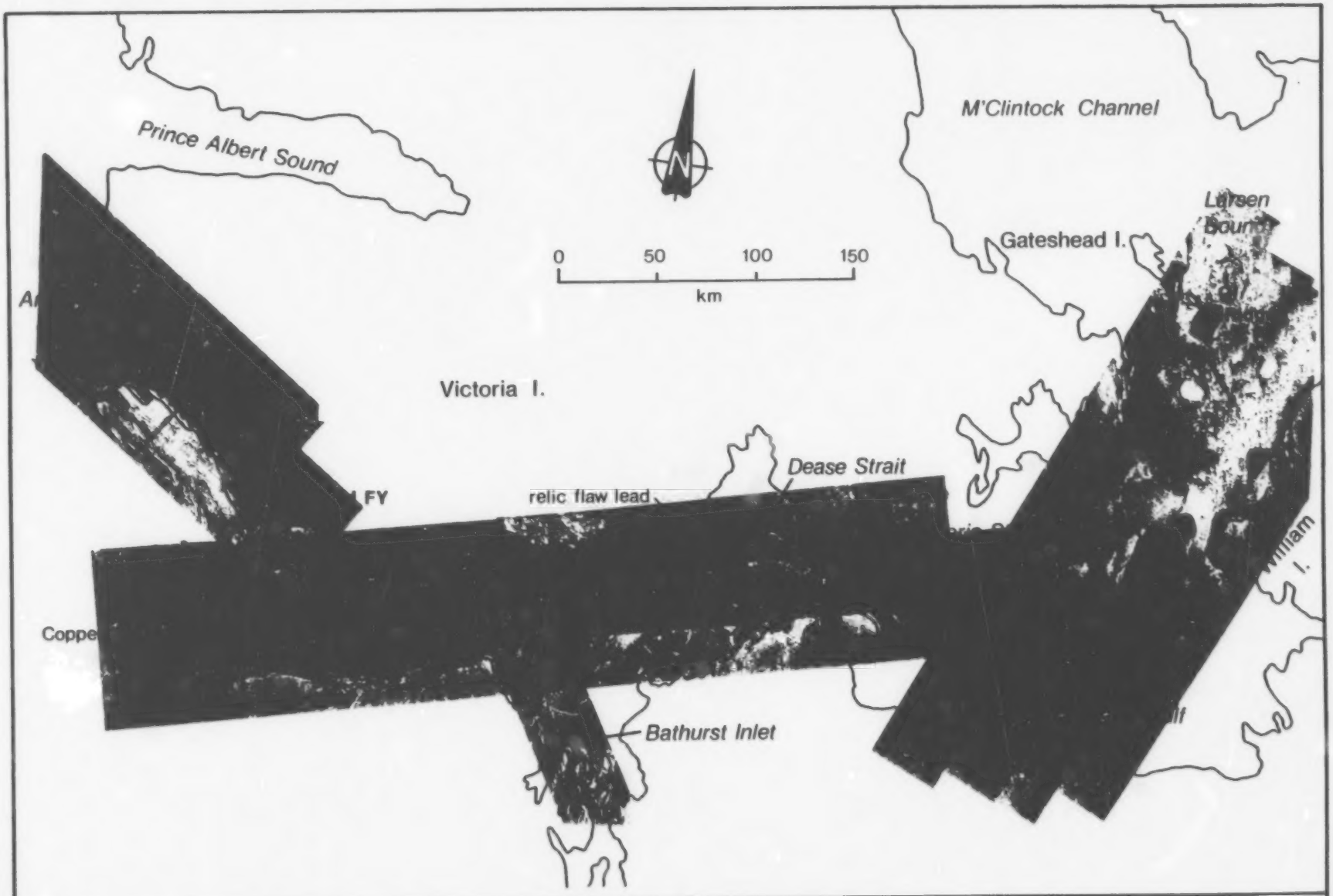

Figure 9: Distribution of Old Ice (OI) and First Year Ice (FY) - Winter 88/89
SAR mosaic of the Southern Route (STAR-1, March 12 - 25, 1989)

Between the November 1988 and March 1989 SAR data acquisitions a number of fractures opened in Victoria Strait southeast of Gateshead Island. This attests to current induced mobility of the ice cover in the region during the winter period. Tidal streams in Larsen Sound meet the shallowing rise in Victoria Strait and occasionally cause regional stresses in a lightly consolidated ice cover. The extent of ridging in southern Victoria Strait does not appear to have increased during the intervening four month period possibly owing to the absence of significant concentrations of old ice floes in the waterway.

The remainder of the deep-draft corridor from Queen Maud Gulf to Amundsen Gulf is characterized by a level first-year ice cover. The relic flaw lead in western Dease Strait dates from the fall period when mobile ice in Coronation Gulf continued to drift westward away from a landfast ice edge in Dease Strait.

5.0 Conclusions

5.1 Bathymetry and Aids to Navigation (NAVAIDS)

A deep-draft corridor with minimum charted depths of 14 metres exists along the Southern Route of the North-West Passage. Peel Sound, Franklin Strait and Larsen Sound contain adequate bathymetry to allow a vessel to navigate freely around difficult ice conditions. Victoria Strait and Dolphin and Union Strait contain charted shoals which dictate that a vessel must follow a rather defined line of soundings through sections of these waterways.

The installation of additional NAVAIDS is recommended to assist with vessel positioning in Icebreaker Channel and Cache Point Channel. The new NAVAIDS listed in Table 3 would improve navigator confidence under all visibility conditions on transits

through the Southern Route.

All soundings in the region are of a reconnaissance nature. The completion of an accurate, controlled bathymetric survey throughout the waterways of the Southern Route would greatly improve the ability of the navigator to manoeuver around charted hazards and difficult ice conditions.

A new series of navigation charts are being prepared for distribution in 1989. These metric charts for the waterways of the Southern Route will however, not contain new soundings.

5.2 Historical Vessel Transits

The experiences of historical vessel transits through the deep-draft corridor of the Southern Route were reviewed. The majority of vessel transits were accomplished during the summer season (August-September). In years characterized by below average melt conditions few vessels attempted and accomplished transits through the region (ie. 1986 and 1987).

The majority of transits in the Southern Route have exploited the shallow-draft corridor through James Ross Strait St. Roch Basin and Simpson Strait however transits by deep-draft vessels were restrictd to Victoria Strait. The absence of charted obstructions west of Jenny Lind Island in Icebreaker Channel (deep-draft corridor) has made this the preferred routing option during more recent transits. Only one vessel (USCG NORTHWIND, 1969) has ever transitted M'Clintock Channel and it appears that a route along the western shore of Prince of Wales Island may be available in extremely favourable years. Peel Sound provides the preferred access to Larsen Sound from Barrow Strait. Passages through Bellot Strait have been attempted historically but often with great difficulty, due to variable

tidal currents and ice conditions.

Generally, the historical record of vessel transits contains very little information on the ice encountered or avoided (age, strength, concentration) during transits through the Southern Route of the North-West Passage. Ice pressure incidents which had a marked effect on vessel progress, or which resulted in structural damage were not documented to a level whereby navigators or ship operators could learn from these difficult transit experiences and develop contingency plans for recognizing the build-up of difficult or ice conditions. Future transits should be carefully documented to accurately define the performance and trafficability of deep-draft vessels through the various year-round ice regimes of the North-West Passage.

5.3 Ice Climatology

Ice conditions in the Southern Route of the North-West Passage have not been investigated in detail. The only general description of conditions for the region is presented in Sailing Directions Arctic Canada (CHS, 1982). Although this description defines average ice conditions (average freeze-up and break-up) very little information is advanced on the anomalous events which produce onerous ice conditions for transitting vessels.

The current Arctic Shipping Pollution Prevention Regulations (ASPPR) restrict vessel entry into Zone 2 (M'Clintock Channel) to vessels above Arctic Class 2, and the shipping access window is among the shortest of all the Canadian control zones. This serves as an acknowledgement of the near persistent old ice regime found in this waterway. The shipping window for vessels throughout the remaining control zones of the Southern Route (Zones 6,7,12) are considerably longer in duration reflecting early break-up and the light old ice concentrations in contrast

to shipping control zones in other sectors of the Canadian Arctic.

The interpretation and analysis of sea ice signatures from Synthetic Aperture Radar (SAR) data collected over three consecutive winters in the Southern Route highlight the drastic variability in ice conditions along the deep-draft corridor of the Southern Route. The low melting degree day accumulations (below average air temperatures) recorded in the eastern Canadian Arctic during the summers of 1985 and 1986 resulted in the persistence of high concentrations of old ice in Larsen Sound and Victoria Strait during the winter of 1986/87.

An average summer in 1987 resulted in the clearing of old ice from the deep-draft corridor predominantly through in-situ ablation. Light concentrations of old ice drifted southward into Victoria Strait late in the summer of 1987 from the minimal break-up of ice in eastern M'clintock Channel. A vessel which may have attempted a winter transit in 1987/88 would have encountered predominantly first-year ice conditions throughout the deep-draft corridor.

An above average break-up year in 1988 resulted in the near complete dispersal of old ice from northern and eastern M'Clintock Channel into Larsen Sound and northern Victoria Strait. Analyses of early winter SAR data delineated a high concentration of conglomerate and uniformly toned old ice floes (various floe sizes) effectively blocking vessel access to southern Victoria Strait. The spectral signature of the ice matrix between the old floes appeared to represent heavily rubbled first-year/old ice. The old ice barrier, while not as extensive in distribution as conditions in the winter of 1986/87, appeared to represent a more difficult ice regime for a winter transit in comparison to winter conditions in 1987/88. A mid-

winter SAR data set captured in Victoria Strait presented evidence of winter mobility. A few large leads had opened in the consolidated ice cover, fracturing several old floes which subsequently re-freezing with first-year ice. All waterways west of Queen Maud Gulf were covered with predominantly level first-year ice.

6.0 Recommendations:

The continued research effort required in order to better understand the limits to year-round navigation through the Southern Route of the North-West Passage include:

A) The execution of detailed ice properties field validation exercises in order to define in engineering terms, the physical properties of winter ice regimes along the deep-draft corridor.

B) Developing a method for defining the implications on vessel trafficability of various deformed first-year ice environments.

C) Continuing the collection of detailed remote sensing data sets of year-round ice conditions in the waterways of the North-West Passage.

D) Investigating the climatologic and oceanographic controls on the distribution and dispersion of sea ice along present and future shipping corridors.

E) Improving the provision of accurate strategic ice information facilitating the selection of efficient routing options by vessel operators attempting passage of either the Northern or Southern routes of the North-

West Passage.

Subsequent phases of the Beaufort Sea Accessibility Study will continue the execution of scientific and operational research aimed at enhancing the ability of vessel operators to safely and efficiently navigate deep-draft vessels in the waterways accessing the Beaufort Sea from the east.

7.0 References:

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Appendix A

Deep-Draft Corridor of the Southern Route of the North-West Passage

The following figures were reproduced from CHS charts and include the deep-draft shipping corridor through the waterways approaches to the Beaufort Sea from the east.

Figure	Area of coverage
A-1	Barrow Strait/northern Peel Sound
A-2	Southern Peel Sound/northern Franklin Strait
A-3	Southern Franklin Strait/Larsen Sound
A-4	Northern Victoria Strait
A-5	Southern Victoria Strait
A-6	Icebreaker Channel/Queen Maud Gulf
A-7	Dease Strait
A-8	Eastern Coronation Gulf
A-9	Western Coronation Gulf/eastern Dolphin and Union Strait
A-10	Western Dolphin and Union Strait/Amundsen Gulf.

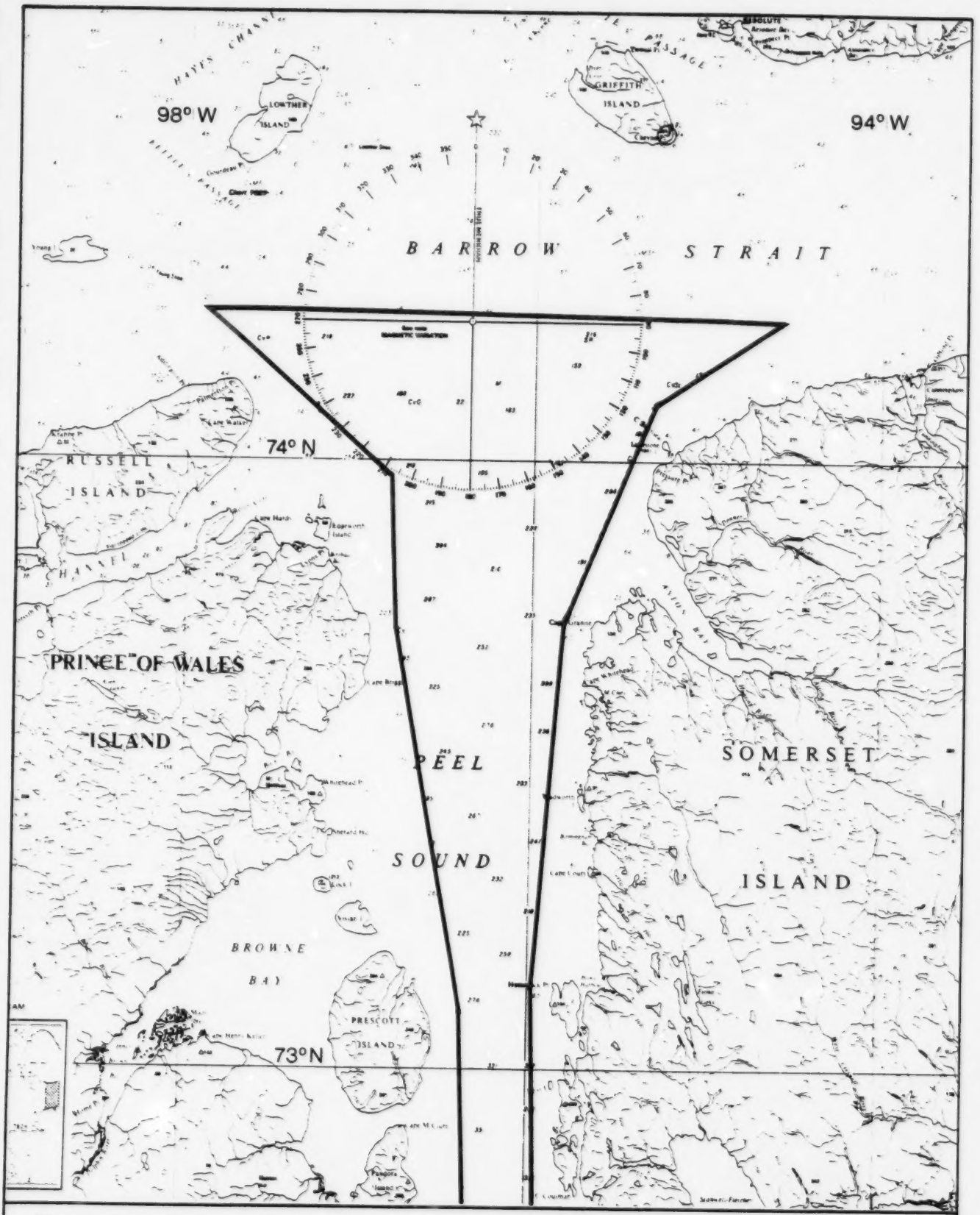

Figure A-1: Deep-draft corridor Depth in meters. Scale 1:880,000
(CHS chart 7830 - Cornwallis Island to Stefansson Island)

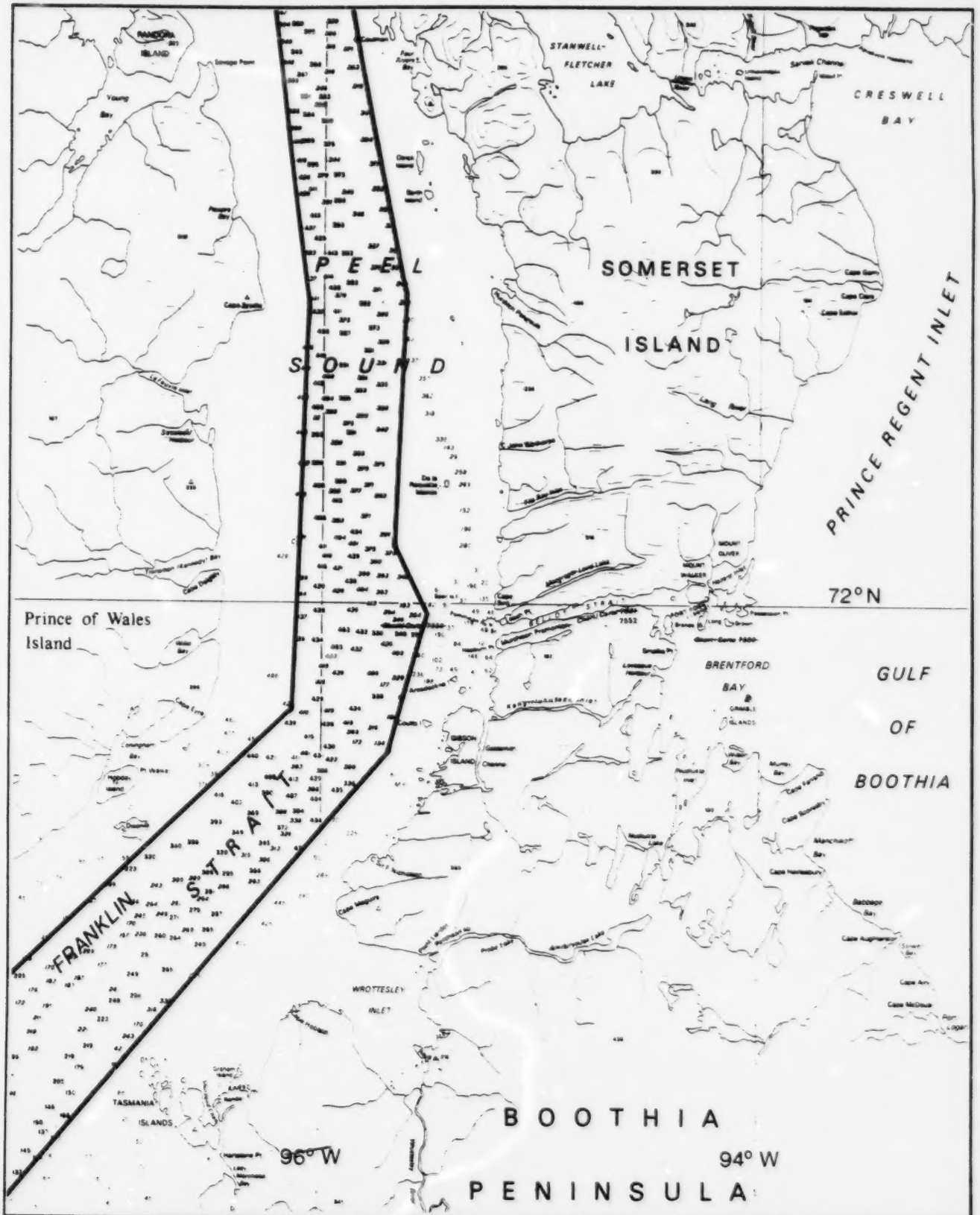

Figure A-2: Deep-draft corridor Depth in meters. Scale 1:880,000
(CHS chart 7740-M'Clintock Channel, Larsen Sound & Franklin Strait)

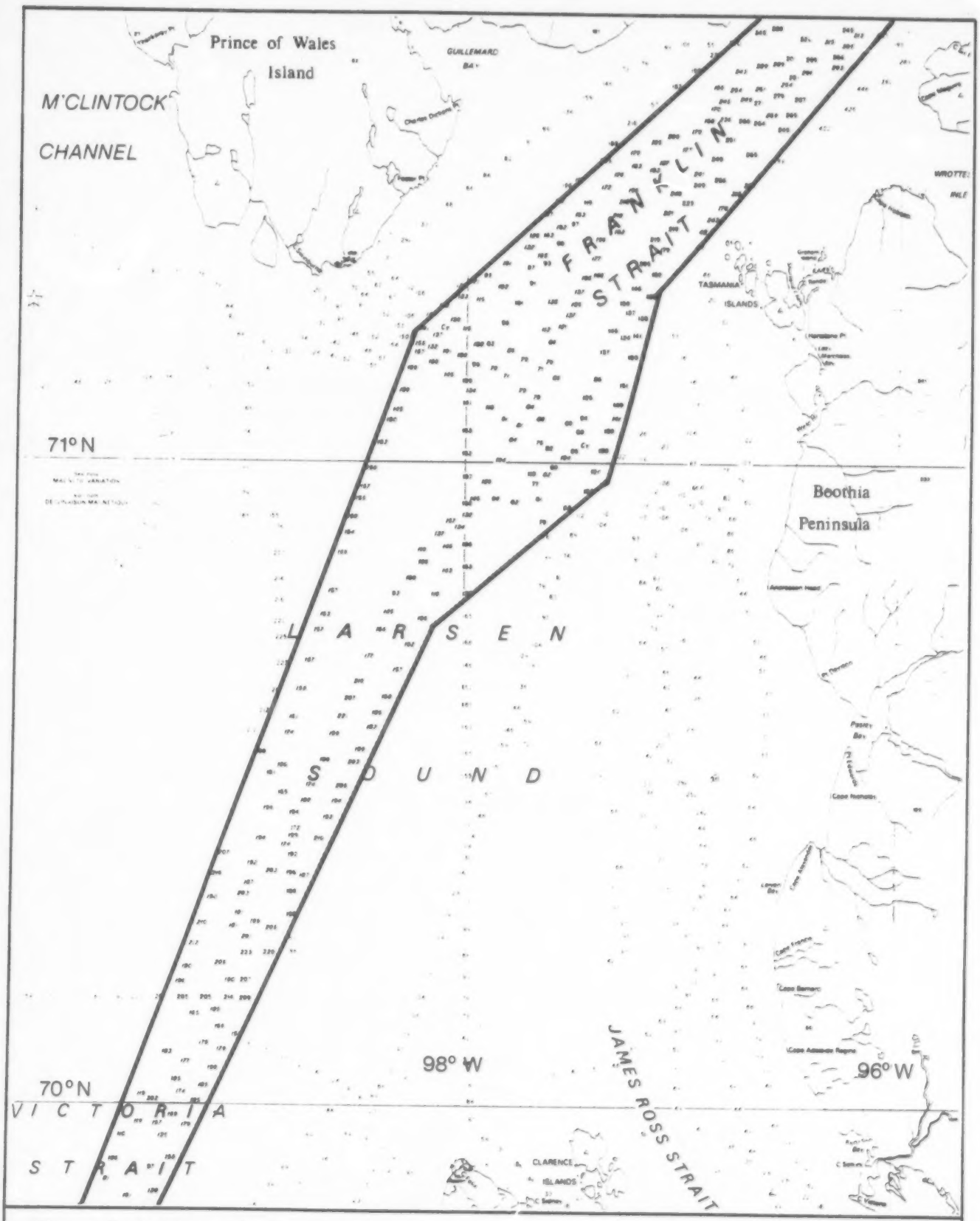

Figure A-3: Deep-draft corridor Depth in meters. Scale 1:880,000
(CHS chart 7740 - M'Clintock Channel, Larsen Sound & Franklin Strait)

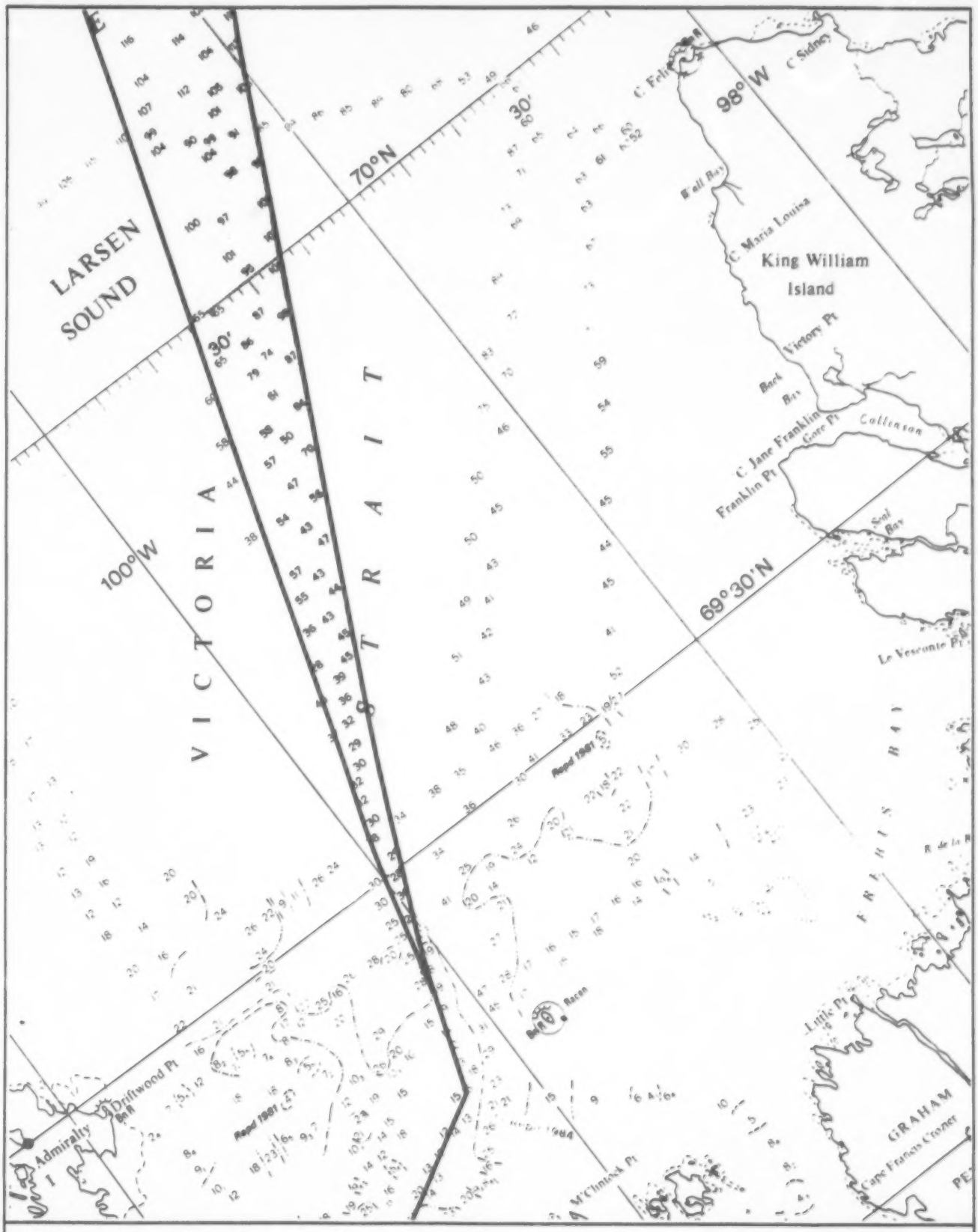

Figure A-4: Deep-draft corridor Scale 1:500,000

(CHS chart 7083 - Cambridge Bay to Shepherds Bay) Depth in fathoms

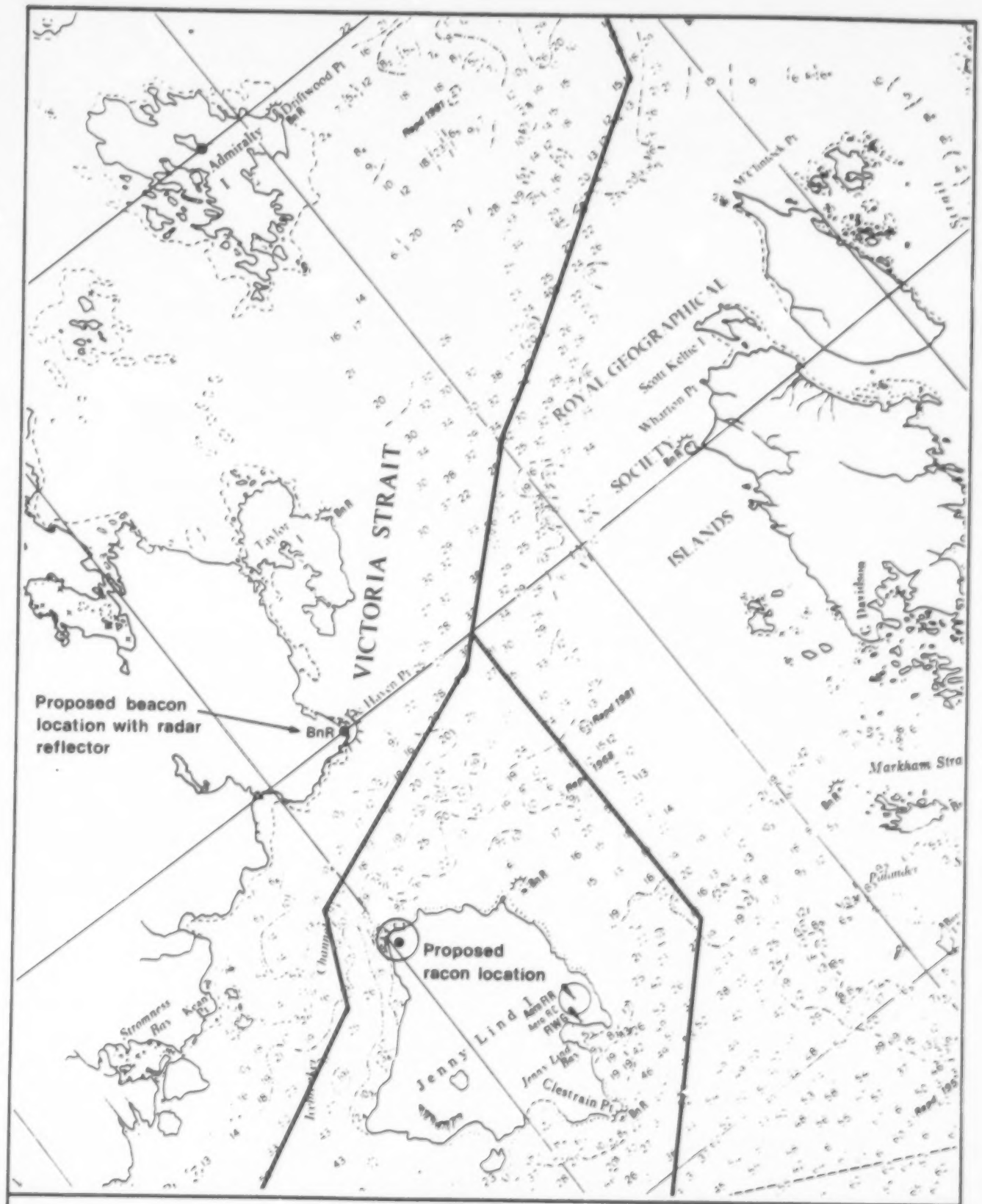

Figure A-5: Deep-draft corridor Scale 1:500,000
(CHS chart 7083 - Cambridge Bay to Shepherds Bay) Depth in fathoms

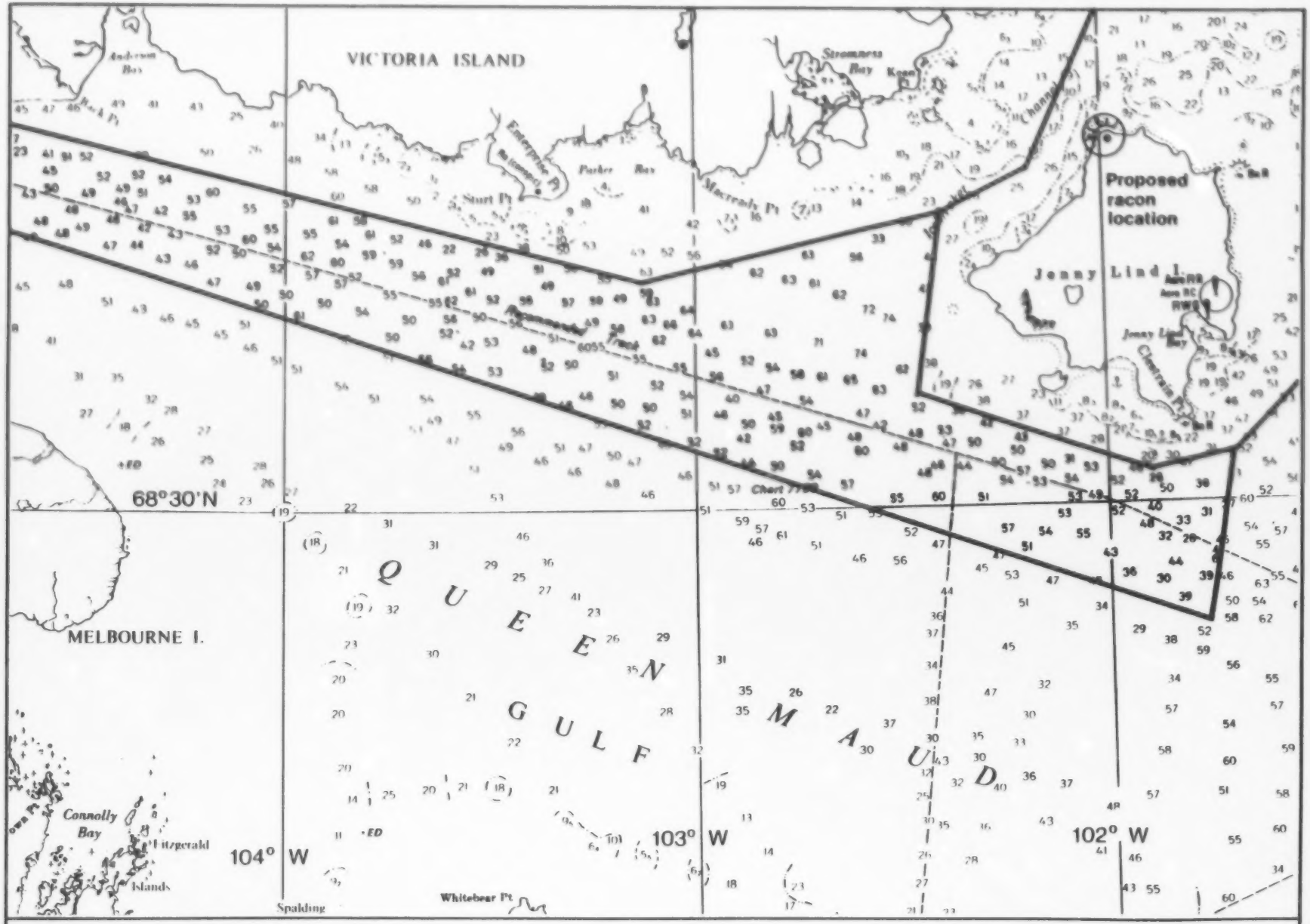

Figure A-6: Deep-draft corridor
(CHS chart 7083 - Cambridge Bay to Shepherd Bay)

Scale 1:500,000
Depth in fathoms

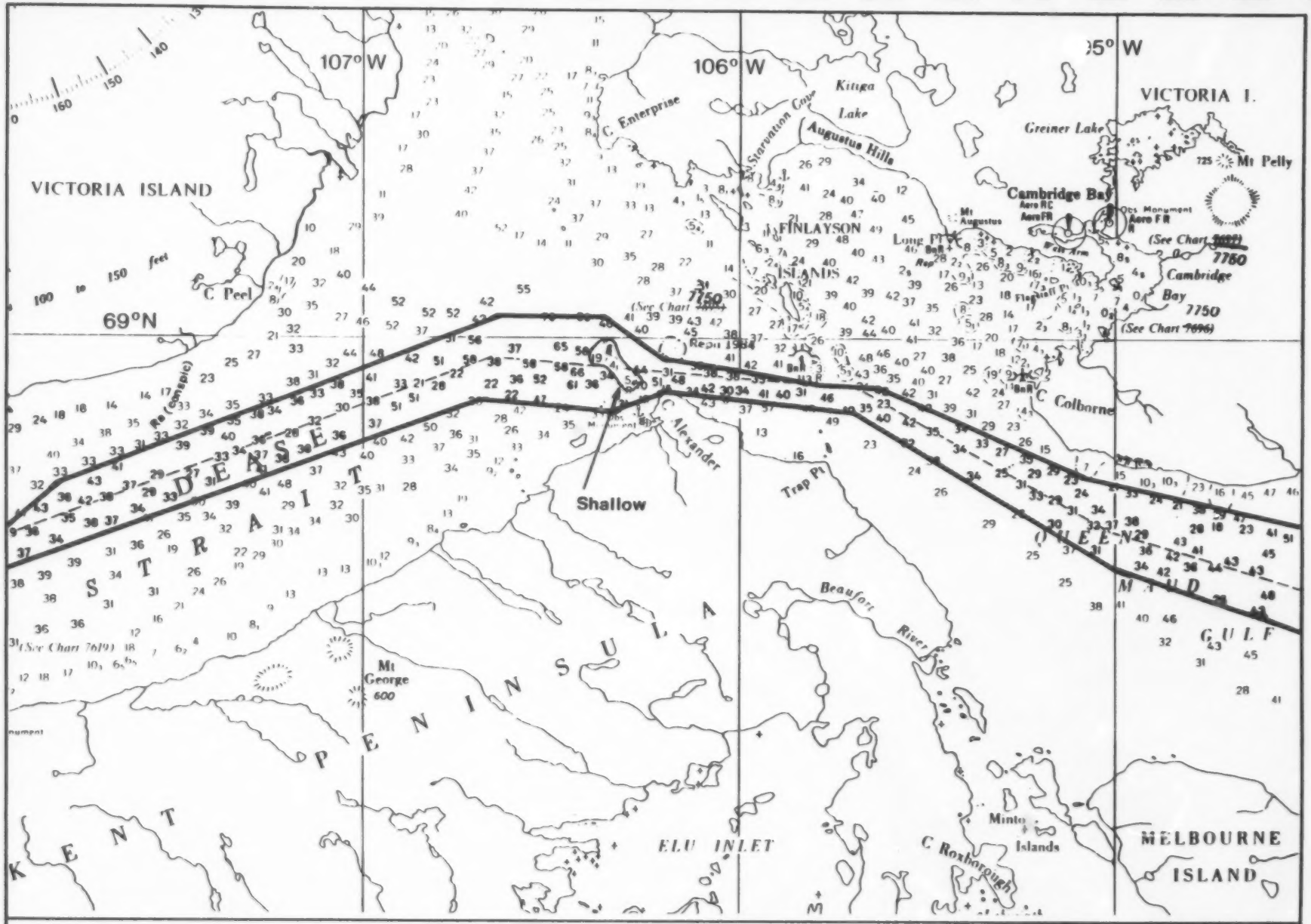

Figure A-7: Deep-draft corridor
(CHS chart 7082 - Cape Baring to Cambridge Bay)

Scale 1:500,000
Depth in fathoms

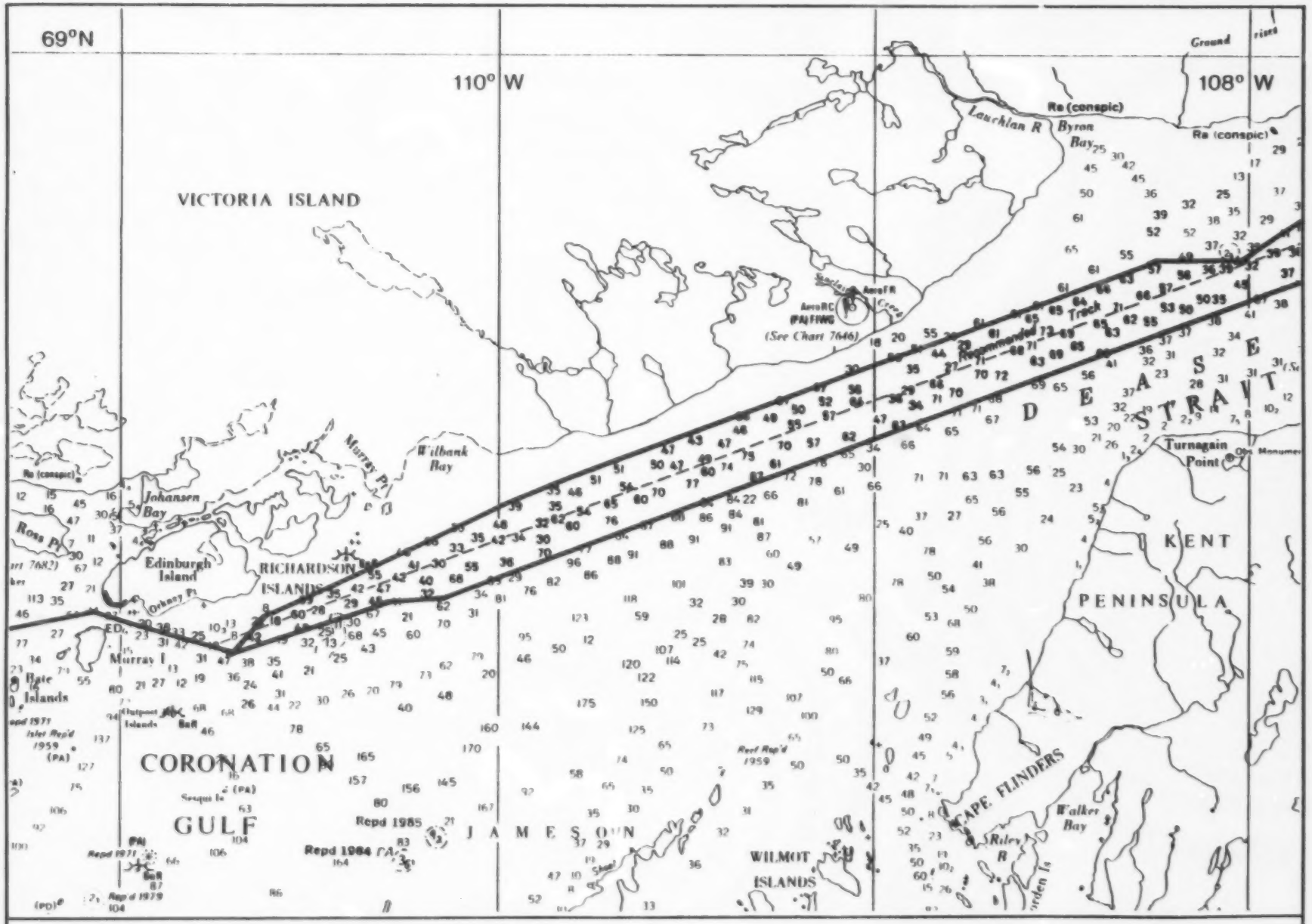

Figure A-8: Deep-draft corridor
(CHS chart 7082 - Cape Baring to Cambridge Bay)

Scale 1:500,000
Depth in fathoms

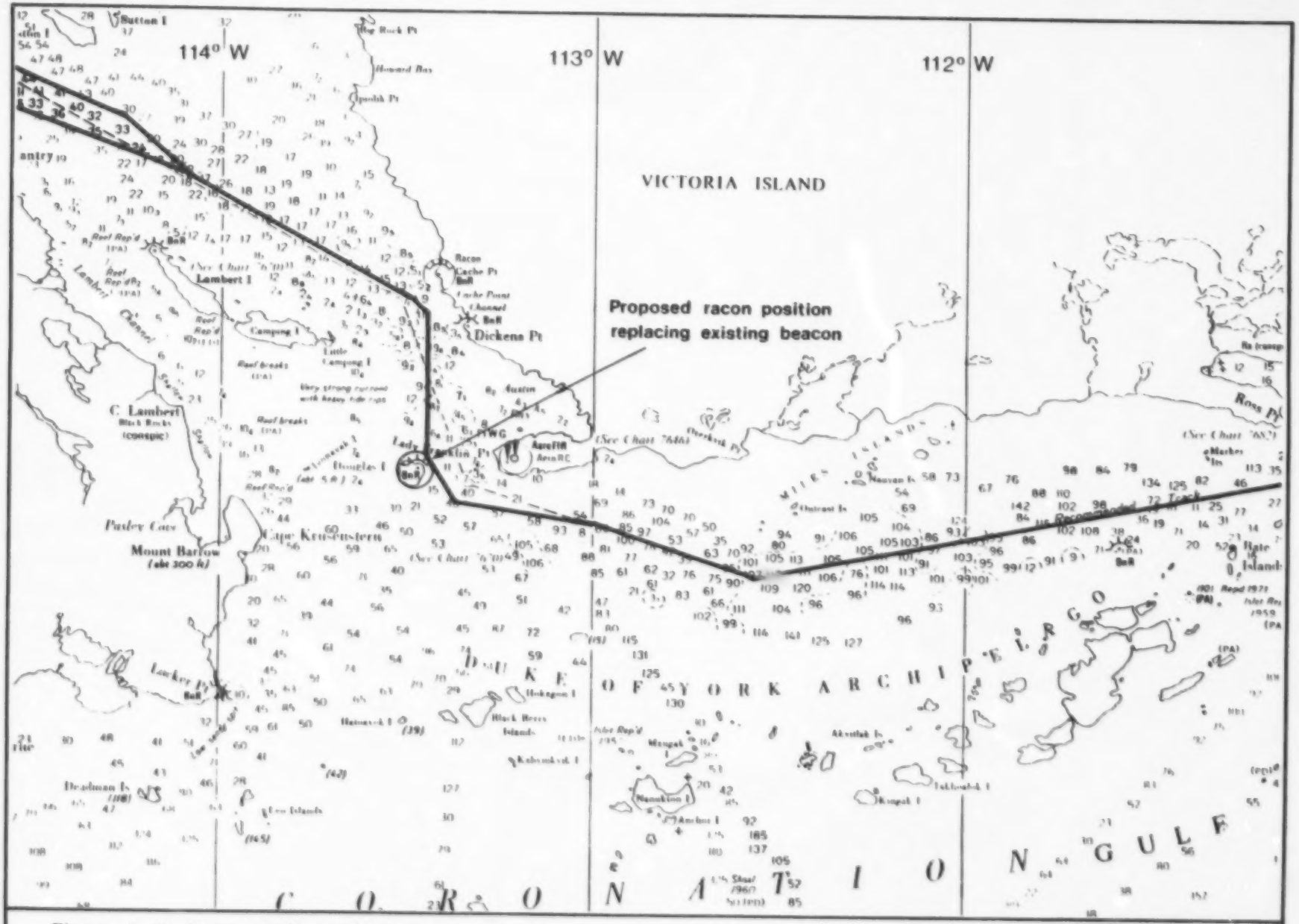

Figure A-9: Deep-draft corridor
(CHS chart 7082 - Cape Baring to Cambridge Bay)

Scale 1:500,000
Depth in fathoms

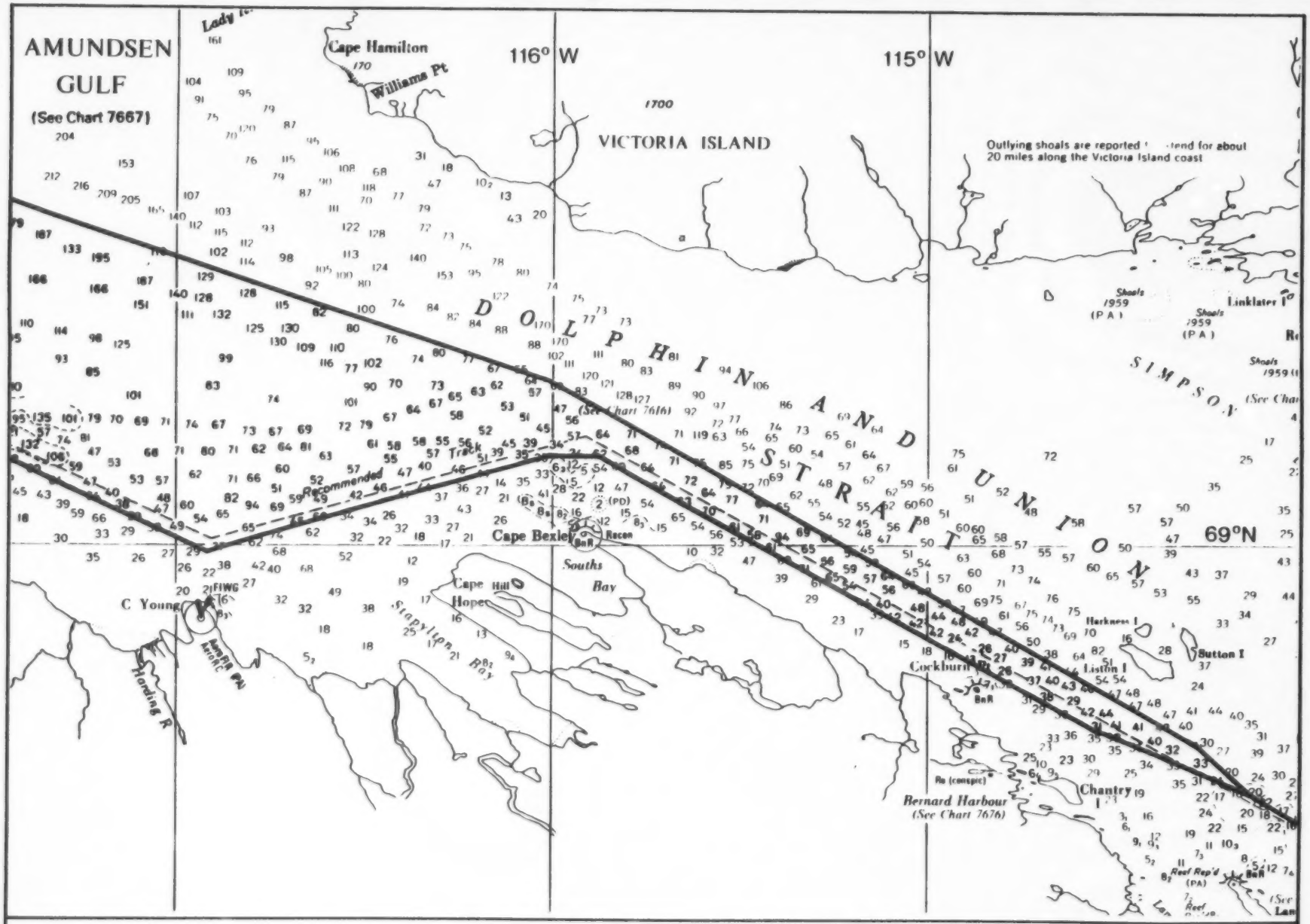

Figure A-10: Deep-draft corridor
(CHS chart 7082 - Cape Baring to Cambridge Bay)

Scale 1:500,000
Depth in fathoms